The influence of neurostimulation on stimulus discrimination: tDCS at Fp3 can modulate old / new recognition and target detection for faces and chequerboards.

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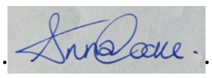
Signature: ….………………………………………..

Abstract

This paper reports the results of three experiments investigating the effect of transcranial Direct Current Stimulation (tDCS), a form of neurostimulation, on stimulus discrimination in an 'old/new recognition' and a target detection task. Experiment 1 presents regular faces alongside a set of manipulated faces, Thatcherised faces, or familiar chequerboards; showing that anodal stimulation can selectively increase or reduce the face inversion effect for regular faces simply by changing the accompanying stimuli. That tDCS can reliably disrupt or enhance performance on an index of facial recognition as robust as the face inversion effect is a significant finding. Experiment 1 also provides the first direct evidence that a set of manipulated faces generalise onto regular faces and do so sufficiently to reduce the inversion effect in the latter. The results are interpreted, using a theory of representational development known as the McLaren, Kaye and Mackintosh (MKM) model, as tDCS altering error-based salience modulation with the effect of enhancing generalisation between within-category stimuli. Experiment 2 extends the analysis offered to a detection task with 'realistic' and standardised faces while Experiment 3 presents familiar chequerboards in the same task. The results show that anodal stimulation has a different effect to that in the 'old/new recognition' task, having no significant effect on sensitivity but an unexpected effect on response bias.

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Chapter 1 : General Introduction

Facial Recognition

Humans have a remarkable ability to process and recognise other human faces. Face processing refers to the ability to understand and interpret the face as a stimulus. Face recognition is a form of processing which allows an individual to attribute an identity to that face stimulus and to recognise it (Maurer, Le Grand & Mondloch, 2002). As research into the nature of face recognition has advanced, the question of whether it is a specialist ability or a more general sub-type of object recognition controlled by general-purpose mechanisms has remained. Evidence to support these positions has emerged from cognitive theories, behavioural experiments, neuropsychological study and more recently, from neuroimaging, neurostimulation and electrophysiology studies.

That unfamiliar faces are much more difficult to recognise than familiar faces has been a topic of great interest as it could suggest that different mechanisms or representations facilitate each. In a research setting, recognising an unfamiliar face most often refers to situations where participants make judgements about whether a previously unknown face being presented has been seen earlier in the experiment. It can also refer to situations where different images of an unfamiliar face are presented and participants have to decide whether they are of the same person (Johnston & Edmonds, 2009). The recognition of familiar faces refers to images of individuals which are known to participants either because they are famous, personally familiar, or because they have been sufficiently familiarised in the experimental context. Johnston and Edmonds (2009) suggest that the difficulties perceivers describe anecdotally in recognising unfamiliar faces points to processing that is quantitively different; a suggestion which makes logical sense given perceivers have less experience with the individual stimuli. However, Johnston and Edmonds (2009) argue that there are also qualitative differences in the way familiar and unfamiliar faces are processed and that these result from differences in the way they are represented. Supporting evidence comes from experimental findings which show changes in pose, expression and context can disproportionately affect the recognition of unfamiliar faces. However, distinctiveness can improve the recognition of both in contrast to inversion, which impairs the recognition of both (Johnston & Edmonds, 2009). These dissociations have been used as evidence of qualitative differences in the processing of familiar and unfamiliar faces, which can account for why environmental factors affect the recognition of each so differently (Johnston & Edmonds, 2009). The experiments presented in this paper relate to unfamiliar face recognition and the processing of experimentally familiar and unfamiliar faces and objects, which has the advantage of allowing experimental control over stimulus familiarity.

The influence of inversion on familiar and unfamiliar face recognition was noted in behavioural experiments conducted in the mid 20th century which repeatedly showed that humans have difficulty recognising inverted faces compared to their upright counterparts. To investigate why this might be so, Yin (1969) designed a series of experiments which led to the discovery of the **face inversion effect;** the better recognition of upright than inverted faces where the difference represents the inversion effect. The face inversion effect is used an index of face recognition and has over decades of study become one of the most robust phenomena in Cognitive Psychology. Yin (1969) aimed to test whether there is a general impairment in recognising upside-down mono orientated objects (objects which clearly have a ‘right way up’) or whether there is something ‘special’ about faces. To do so, Yin's experiment used a ‘forced-choice recognition memory task’ where participants were shown images in an ‘inspection series’ after which, during the ‘test series’, they had to choose which image out of the pair presented had been previously shown. In the first two experiments, standardised images of faces were presented with images of houses and caricatures of planes and men in motion. In the final experiment, in order to remove difficulty as a potential explanation for why the upright faces were consistently recognised better than any of the other stimuli classes, artist's line drawings of faces were created and presented alongside drawings of faceless figures in different period costumes. The results revealed an inversion effect for the mono orientated objects such that stimuli were recognised better when upright than inverted. However, the effect of inversion was largest for faces where in all the experiments, the upright faces were recognised best of all the stimuli and the inverted faces worst. These results led Yin to argue that inverted faces are especially difficult to remember as a result of two factors; "a general factor of familiarity with mono orientated objects" and a "special factor involving faces" (Yin, 1969, p. 145).

However, soon after Yin published his results, new studies disputed the existence of a 'specific' inversion effect for faces and instead presented an 'expertise' account. The 'expertise' account suggested that inversion effects could be elicited in response to other objects so long as the perceiver had significant experience with that class of stimuli. For example, Diamond and Carey (1986) challenged the notion that faces were unique in the size of their inversion effect. Yin's study found that the recognition of upright faces was 25% greater than that of inverted faces. This was compared to a range of 2-10% with the other familiar mono orientated stimuli (Diamond & Carey, 1986). In Experiment 2, Diamond and Carey (1986) investigated the relationship between expertise and the size of the inversion effect elicited by pictures of dogs and human faces in experts (breeders, handlers and judges) and novices. Whole-body photographs of three breeds of dog were taken from the American Kennel Club archives. Images of human faces were taken from college yearbooks where half were male and a half were female. Using a forced-choice recognition paradigm, participants inspected a series of photographs before moving onto the forced-choice series where they had to select which image of a pair they had seen before. This procedure was carried out first on the upright images and then on the inverted images, which were all shown in a separate inspection and forced-choice series rather than being intermixed. It is also worth noting that some of the recognition images were different to the inspection series images, though they showed the same individual dog. This was to discourage recognition on the basis of the picture rather than the individual. The results showed that dog experts and novices recognised upright human faces significantly better than inverted human faces. However, while experts recognised upright dog images significantly better than inverted images, this advantage for the upright images was absent in the novice group. This result was replicated in Experiment 3 where the experts were shown images of breeds with which they specifically were familiar. The authors concluded that vulnerability to inversion specifically affects dog-experts compared to novices. Therefore, providing perceivers are sufficiently familiar, recognition of a different stimulus category is as sensitive to inversion as faces. This suggested a large effect of inversion might not be specific to faces.

In their 1986 paper, Diamond and Carey argued that stimuli need to possess certain characteristics for an inversion effect to emerge. Using faces as an example, they suggested that all faces possess both featural and configural information. Featural information refers to the individual elements of the face, such as the nose or mouth while configural information is made up of first and second order relational information. First order relational information is described as the standard spatial relationships between the features of an object which allow a perceiver to classify it as a member of a certain stimulus class. For example, that two eyes are orientated above a mouth in the face. Second order relational information refers to the minute special variations in first-order structure which allow different individuals of that category to be identified (Civile, McLaren & McLaren, 2011). Some researchers now also refer to a third type of configural processing, holistic processing, which describes the 'gluing' together of features into a whole, or gestalt. Configural processing generally refers to the perception of relationships between the features of a stimulus whereas featural, componential or analytical processing refers to the processing of individual features (Maurer, Le Grand & Mondloch, 2002). The expertise account would suggest that the skill adults show in recognising other human faces is achieved by years of experience processing both the individual features and the spatial relationships between them (Maurer, Le Grand & Mondloch, 2002). Indeed, Diamond and Cary (1986) argue that some stimuli, for example faces or dogs, clearly share a standard spatial relationship in their first order information. Characterised in another way, the stimulus category is defined by a prototype. In the case of faces, or images of dogs, perceivers who have sufficient experience with these prototype-defined categories of stimuli have an improved ability to distinguish between individual members from those categories compared to novices because they can exploit the second order information to make individuation judgements. An effect which disappears upon inversion as the effect of experience is negated (Diamond & Carey, 1986). Therefore, Diamond and Carey (1986) suggest that three conditions need to be met to achieve a comparable inversion effect in a non-facial stimulus category; that exemplars share a basic configuration, that these exemplars can be individuated on the basis of second-order relational information and that perceivers are sufficiently familiar with the stimulus category which allows them to exploit the information.

Gauthier and Tarr (1997) subsequently investigated the effect of expertise on sensitivity to this configural information using 'Greebles'; an experimental analogue of human faces. In this experiment, participants randomly selected to be 'Greeble' experts were familiarised with 30 individuals by being shown an image and categorising it along three dimensions; family, gender and individual; each of which had been given a nonsense-word name. Participants had to reach a pre-specified criterion to be considered 'expert' which took on average 7-10 1-hour training sessions. In the test phase, experts and novices were shown images of unfamiliar 'Greebles' (i.e. not previously seen by the experts during training) which had been manipulated to create two versions. The first version was unmanipulated (studied-configuration) and the second moved the top pair of parts 15 degrees about the vertical axis (transformed-configuration). Three distractors were then created for each target where one of three parts was replaced by a distractor called a 'foil'. Finally, three images of each target were created showing each target and foil part on their own. Novices in the test phase first learned the names of the three Greeble 'body' parts; *boges, quiff* and *dunth* before moving onto the forced-choice recognition phase. Participants learnt the names of 6 upright 'Greebles' (e.g. *Pimo*). Forced-choice recognition of the parts was then tested by an instruction appearing on the screen e.g. '*Pimo's Boges*' and participants chose which of two images showed that command. After completing the experiment with upright 'Greebles', participants followed the same procedure with inverted 'Greebles'. Experts followed the same procedure after completing the familiarisation training. The results showed that both novices and experts were better at recognising individual 'Greeble' parts when they were presented in their original configuration than in isolation. This suggests the visual properties of the stimulus were more important than perceiver's level of expertise. 'Greeble' experts were also better at recognising parts when they were in the studied than the transformed-configuration and were slower in the transformed-configuration condition. Both effects were absent in novices and in the inverted condition. These results suggest that expertise training with 'Greebles' confers specific advantages which are very similar to those seen with faces. 'Greeble' experts were faster, more accurate and more sensitive to configural changes than novices which lead the authors to conclude that 'Greeble' experts used similar mechanisms, fine-tuned by experience, in this task to the ones used in facial recognition. These studies supported the 'expertise account' as an explanation, or at least contributing factor for, the existence of inversion effects which was taken as contradicting the idea of faces being in some way special.

Yet despite theories which seemed to be able to account for similar results between faces and other objects, there was also evidence to support the existence of a special kind of configural processing with faces, the most convincing being the 'composite face effect'. The 'composite face effect' describes the phenomenon where participants are faster and more accurate at recognising the top half of one face when it is presented misaligned (laterally offset) than when presented in composite with the bottom half of another face. The effect is generally used to suggest that the features of an upright face are so strongly linked together that they are processed holistically, making feature-by-feature comparisons very difficult (Maurer, Le Grand & Mondloch, 2002). Further evidence for configural processing of faces comes from studies showing that individual features are recognised at about 10% greater accuracy when presented in the context of a whole face rather than in isolation, suggesting there is something special about the way faces are processed (Maurer, Le Grand & Mondloch, 2002). Inversion has also been shown to disrupt the use of configural information. For example, Leder and Bruce (1998) used featurally-distorted faces (e.g. darkened lips) and configurally-distorted faces (e.g. shorter distance between the mouth and nose) to investigate the effect of distortions on distinctiveness judgements and how this in turn interacted with inversion. The study found that both featural and configural distortions of upright faces increased distinctiveness judgements. However, upon inversion, locally-distorted faces remained distinctive (indicated by higher distinctiveness ratings) whereas configurally-distorted faces lost their distinctiveness. The authors argue that the results point to inversion disrupting a specific type of processing, rather than a general mechanism (Leder & Bruce, 1998). Overall then, the face inversion effect has been used as strong evidence for configural processing of faces. It suggests that upright faces are processed holistically and that inversion removes or reduces this ability, meaning that perceivers must revert instead to featural processing to achieve recognition.

The inversion effect vs. the face inversion effect

McLaren (1997) instead investigated whether a general purpose associative mechanism could explain the inversion effects found in faces and other familiar mono orientated objects. Experiment 1 in that paper used a categorisation followed by a discrimination phase where the stimuli were prototype-defined sets of chequerboards. During the categorisation phase, subjects sorted chequerboard exemplars into two categories, which were prototype-defined, on the basis of response feedback. This pre-exposed participants to some of the stimuli in those categories. Then, in the discrimination phase, participants were shown pairs of chequerboards split by the following conditions; upright exemplars drawn from one of the familiarised categories (though not ones that had been pre-exposed in the first phase), inverted exemplars drawn from the same familiarised category, and upright and inverted exemplars drawn from a novel (not pre-exposed) category. The results showed a significantly larger inversion effect for the familiar chequerboards compared to the novel ones. Furthermore, familiar upright exemplars were recognised better than novel upright exemplars and conversely, familiar inverted exemplars were recognised significantly worse than novel inverted exemplars (McLaren 1997 Experiment 1a). Experiments 1a showed that experience with a category defined by a prototype improves the perceiver's ability to distinguish between other exemplars taken from that category. The advantage is lost on inversion and in fact incurs some cost (McLaren, 1997), in a very similar way to Yin's results with faces.

Experiment 2 investigated whether the inversion effect found in the first experiment would generalise to a recognition paradigm. Participants completed the categorisation task followed by a delayed matching task. In the delayed matching task, a category exemplar (either upright or inverted) was shown, followed by a mask, followed by a second exemplar in the same orientation from the same category as the first. Half the participants saw all exemplars drawn from a familiar category, half from a novel category. Those in the novel group had learnt to categorise stimuli shown to the equivalent subject in the familiar group before being shifted to a different test phase. Participants had to decide whether the second exemplar was the same or different from the first as quickly as they could. The result showed that participants in the familiar group were significantly better at making same/different judgements for upright compared to inverted exemplars. Performance on familiar upright exemplars was also significantly better than on novel upright exemplars. The authors concluded that category familiarity can create an inversion effect in a recognition paradigm and that the resulting inversion effect with novel stimuli is analogous to the one obtained with faces. However, the authors conclude "there is more to face recognition than is captured by the elemental, associative account offered in this paper" (McLaren, 1997, pg. 272) in a strikingly similar vein to Yin in 1969.

Perceptual Learning and Facial Recognition

Over four experiments, Civile et al. (2014) replicated and extended the experiment by McLaren (1997) to integrate what was known about perceptual learning with what was also known about the face inversion effect. Perceptual learning can be defined as the enhanced ability to distinguish between stimuli after experience renders them, or the category they are exemplars of, familiar (McLaren et al., 2016). Civile et al. (2014) used chequerboard stimuli in the '*old/new* *recognition* 'task, a standard paradigm used in the face recognition literature. The '*old/new recognition*' task comprises a 'study 'phase where stimuli are shown to the participant but no response is required and a 'recognition 'phase where the same stimuli presented in the 'study 'phase are intermixed with the same number of new (unseen) stimuli and participants make a judgement as to whether they have seen a particular exemplar before ('old' response) or not ('new' response). The results from Experiment 1a showed an inversion effect for familiar chequerboards could be obtained using the standard '*old/new recognition* 'paradigm which was absent for novel chequerboards. The inversion effect being contingent on familiarisation with the category and the category being prototype-defined, as in McLaren (1997).

Experiment 2 used 'clumpier' chequerboards in order to make the stimuli easier to recognise, as the results from Experiment 1 suggested the task might be too difficult as performance was close to floor. The results confirmed that an inversion effect could be obtained with familiar, prototype-defined categories of chequerboards and furthermore suggested that the inversion effect was made up of two parts; an advantage for prototype-defined upright exemplars from a familiar category and a disadvantage for inverted prototype-defined exemplars from a familiar category (compared to novel/not-familiarised inverted exemplars) (Civile et al., 2014). This evidence drew some convincing parallels between the inversion effect for chequerboards and for faces, strengthening the case that face recognition in humans is at least partly based on general mechanisms that also operate for non-facial stimuli, regardless of whether some extra special processing of faces also occurs.

The McLaren, Kaye & Mackintosh model; a theoretical analysis of a general mechanism underlying face recognition

The McLaren, Kaye & Mackintosh (MKM) model is a theory that attempts to explain how perceptual learning occurs. Perceptual learning leads to an enhanced ability to distinguish between similar stimuli and reduced generalisation between them. The MKM theory begins with the tenet that all stimuli, regardless of their simplicity or complexity, should be conceptualised as a set of elements which are rapidly processed in parallel (McLaren, Kaye & Mackintosh, 1989). *Figure 1* is taken from the 1989 paper and shows a diagrammatic representation of two similar stimuli and their elements. Each stimulus contains elements common to the stimulus category (x) and unique elements (a, b) which mark it as distinct from the prototype of that category, or other exemplars in the category. As a stimulus occurs in the environment, associations between its elements build up. The particular elements that appear will be random, because each stimulus will have a different set of unique elements and a random set of the common elements. But with repeated exposure of the same stimulus, though exactly the same elements may not be activated every time, those present will associate together to form a kind of central tendency. This mechanism explains how a prototypical representation of a category is formed. As the common elements appear most often, they are strongly predicted by the other common elements present. As such, they have a low error term and their salience (which is higher for high error) declines over successive presentations relative to the unique elements; meaning they are less able to support learning. Thus, the common elements are subject to **latent inhibition**. In contrast, the unique elements maintain higher salience because they have weaker connections to the central tendency, they are less strongly predicted by the other elements, and they are experienced less often. The unique elements consequently have the salience necessary to support learning and this leads to an enhanced ability to discriminate between similar stimuli, because the differences in their representations come to dominate learning.

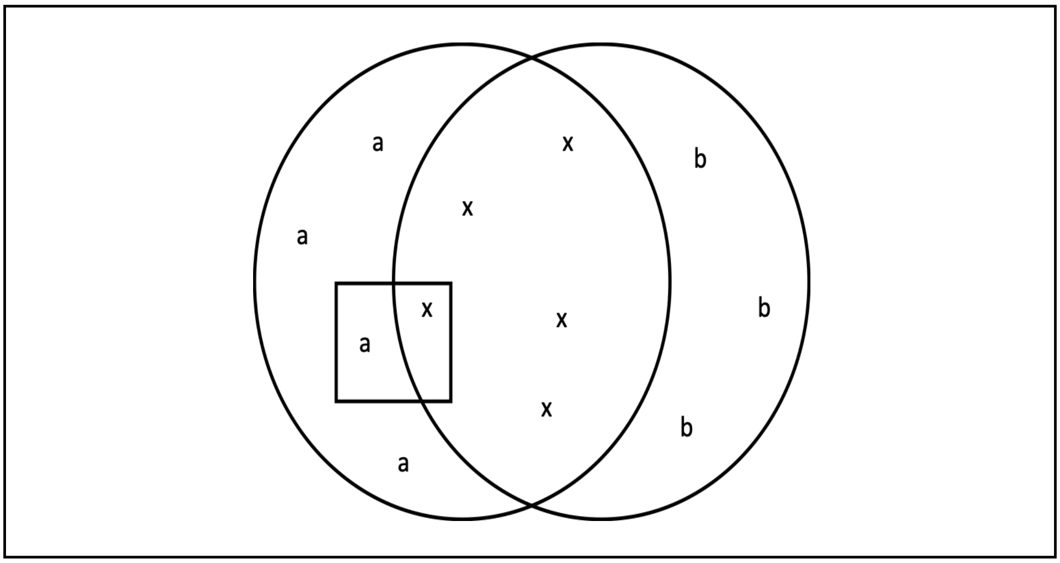

Figure 1. **A diagrammatic representation of two stimuli, adapted from McLaren, Kaye and Mackintosh (1989).**

The MKM theory also posits a **modulator**; a system which determines the associability of a particular element by comparing its internal and external inputs to compute error. Elements within a stimulus receive two types of input; internal (from other elements) and external (from the environment/context). The modulator acts to detect the difference between external and internal inputs and enhances the activation of an element if the difference is large. Equally it enables latent inhibition of the common elements by reducing their salience whilst maintaining the comparatively higher salience of the unique elements. This process has the effect of reducing generalisation between the common elements of two stimuli, and as more generalisation would make it harder to discriminate between the stimuli, reducing it would make them easier to differentiate (McLaren, Kaye & Mackintosh, 1989).

Transcranial Direct Current Stimulation (tDCS)

tDCS is a form of non-invasive brain stimulation which applies a weak direct electrical current (typically 1-2mA intensity) through electrodes usually placed on the scalp (Woods et al., 2016). tDCS changes the threshold that stimulated neurones discharge at which modulates their spontaneous firing rates. This is different to transcranial magnetic stimulation (TMS), for example, which can directly cause an axon or neuron to discharge (Woods et al., 2016). Anodal stimulation induces depolarization making neurones near the firing threshold will become more likely to fire. In contrast, cathodal stimulation induces hyperpolarisation making neurones near the firing threshold become less likely to fire (Miniussia, Harrisc & Ruzzolid, 2013). Therefore, tDCS modulates whatever state the network is in at the time of stimulation as it primes the network by increasing or decreasing cortical excitability (Miniussia, Harrisc & Ruzzolid, 2013). Having said this, the characterisation of anodal stimulation as excitatory while cathodal stimulation is inhibitory is based on evidence primarily looking at stimulation of the motor system. Some experiments examining non-motor areas have found the opposite. It seems important, therefore, to move away from adopting a simple mechanistic approach which maps tDCS directly onto behavioural outcomes. Most especially given that the effect on the affected neurones is unclear as indeed are the downstream behavioural outcomes (Miniussia, Harrisc & Ruzzolid, 2013). Control conditions for a specific montage can be achieved by using an active control study which uses the same tDCS procedure but instead places the active electrode over a different brain area thought to be unrelated to the task or target behaviour. Alternatively or additionally, a sham control condition can be used. Sham conditions typically use the same stimulation ramp-up and down which leads participants to think they have received stimulation because they feel the same itching and/or tingling sensation as the active group. However, the total stimulation period is significantly shortened so as to avoid inducing any significant changes in cortical excitability (Woods et al., 2016).

tDCS and the inversion effect

Civile et al. (2014) showed that an inversion effect for stimuli from a familiar, prototype-defined category, could be elicited during an '*old/new'* recognition task. Civile et al. (2016) introduced tDCS to the chequerboard '*old/new'* recognition task to investigate whether anodal stimulation might have any effect on the inversion effect, and consequently perceptual learning.

The montage was adapted from Ambrus et al. (2011). As the chequerboards used in this experiment were exemplars created from prototype defined categories, and because the formation of a prototype is a prerequisite for perceptual learning according to the MKM theory, the montage used by Ambrus et al. (2011) was deemed plausible as a method of disrupting perceptual learning. Accordingly, Civile et al. (2016) applied anodal stimulation to left dorsolateral prefrontal cortex (DLPFC) at Fp3 at 1.5mA intensity for a total of 10 minutes in the anodal group and 30 seconds in sham. The stimulation intensity was increased from 1.0mA in the original paradigm to 1.5mA in the hope of increasing the magnitude of the effect. The reference electrode was placed over the right forehead above the eyebrow. The results from Experiment 1 showed a significant inversion effect in the sham condition where familiar upright chequerboards were recognised significantly better than inverted ones (Civile et al., 2016). Whereas the inversion effect for novel chequerboards was not significant. The sham condition represented a replication of the experiments by Civile et al., (2014). In the anodal condition, however, there was no significant inversion effect for chequerboards from the familiar category and the opposite effect to perceptual learning was observed numerically, where recognition of the novel upright exemplars was numerically higher than familiar upright exemplars in the anodal condition. Experiment 2 showed the same pattern of results as Experiment 1; a significant inversion effect in the familiar group with upright exemplars being significantly better recognised than the inverted ones in sham as well as cathodal tDCS groups. This effect was absent in the novel group. Whereas in the anodal group, there was no significant inversion effect, and again there was evidence that performance was higher for the novel exemplars compared to the familiar ones. Anodal tDCS compared to cathodal or sham stimulation, therefore, appeared to abolish the perceptual learning that would otherwise occur as a result of exposure to the relevant category.

The results from the familiar upright condition suggested that tDCS somehow influenced the way the stimuli were processed. The results showed that instead of discrimination of familiar upright exemplars improving with repeated exposure as the standard perceptual learning effect would predict, and as appeared to be the case in the sham and cathodal groups, with anodal stimulation, recognition was numerically worse. Furthermore, the anodal group showed higher performance on the novel upright exemplars compared to the upright familiar ones. These two observations suggest that **anodal stimulation increased generalisation** between stimuli in the familiar category. It seemed to go beyond abolishing perceptual learning, as the increased generalisation lead to the novel upright exemplars being better recognised than familiar upright exemplars, rather than them being recognised the same as would otherwise be expected. The study also showed that tDCS administered during the pre-exposure phase can affect performance afterwards; as in the test phase and discredits the idea that tDCS simply has a generally deleterious effect on performance or reduces overall learning. While d' sensitivity scores (a measure of performance accuracy independent of response bias) were lower for the familiar category exemplars in the anodal condition of Experiment 1, the d ’for the novel category exemplars was higher than sham. In Experiment 2, they did not differ significantly. Using the MKM theory to accommodate the results, the authors argue that under standard learning conditions where perceptual learning can be expected to apply, the salience of the prototypical features of a stimulus are reduced via the modulator, leaving the salience of the unique elements comparatively high which enhances stimulus discrimination. tDCS seemed to disrupt this process so that the same associations previously producing low error terms in the prototypical features (which led to low salience) instead simply boosted their overall activation. This has the effect of increasing the salience of the prototypical features, enhancing generalisation between them, and rendering the familiar stimuli more perceptually similar and harder to distinguish. Inverted stimuli, however, remain unaffected because, as an ‘unfamiliar’ category, the usual perceptual learning effect of enhanced discrimination is not present anyway. Thus, the inversion effect is reduced by anodal tDCS, specifically by reducing performance for the upright stimuli, compared to sham.

tDCS then seemed to selectively affect exemplars from the familiar category rather than simply having a generally negative effect on performance and learning. It also had a null effect on the inverted exemplars given the comparative lack of familiarity with the stimulus category. As tDCS was shown to abolish the inversion effect with chequerboards, the results suggested that it might also be able to abolish the inversion effect with faces; one of the most robust phenomena in Cognitive Psychology and, perhaps more intriguingly, presented a new method of enquiry into the role of perceptual learning, if any, in facial recognition (Civile et al., 2016).

tDCS and the face inversion effect

In 2018, Civile and colleagues applied the same tDCS paradigm to the '*old/new recognition*' task this time with faces, to see whether anodal tDCS could reduce the usually robust face inversion effect. In the 'study' phase 64 upright and 64 inverted male and female faces were presented. In the 'recognition' phase, the same 128 faces shown in the study phase were presented again (64 upright, 64 inverted) intermixed with 128 new male and female faces split by the same conditions. As in Civile et al. (2016) tDCS was applied to Fp3 at 1.5mA current for a total of 10 minutes in the anodal condition and 30 seconds in sham. Experiment 1 and 2 revealed a significant inversion effect in sham and a **reduced but still significant inversion effect in the anodal group**. The reduction was driven by significantly reduced recognition of upright faces in the anodal group compared to sham which was analogous to the results with the chequerboards. Importantly, while the inversion effect was significantly reduced in the anodal group compared to sham, it was not abolished as seen with the chequerboards. The inverted faces were also not significantly influenced by anodal stimulation and recognition remained above chance, therefore, supporting the assertion that the tDCS procedure disrupts perceptual learning and actively changes the way stimuli are processed rather than just having some generally deleterious effect on recognition. The same pattern of results was achieved by Civile, Obhi & McLaren (2019).

Experiment 3 established that the effects of tDCS on perceptual learning depend on stimulating Fp3 specifically. In an active control experiment, the same tDCS procedure was applied to the same '*old/new recognition'* task using faces. However, instead of targeting Fp3, the active control study placed the anodal channel at the crossover point between T4-Fz and F8-Cz in the 10–20 EEG system which corresponded to the right-Inferior Frontal Gyrus (rIFG). rIFG specifically was chosen because there were no previous studies implicating it in performance on a perceptual learning task. This made it an appropriate target area to test whether the same stimulation to a different brain region would produce similar effects. The results from Experiment 3 revealed a significant inversion effect in the sham and anodal groups, and a non-significant interaction between them. This showed that the same tDCS stimulation to a different brain area did not reduce the inversion effect as reliably seen in the anodal groups of Experiments 1 and 2 and supported the use of the Fp3 montage in future experiments.

Theoretical analysis, according to the MKM theory, of how tDCS reduces the face inversion effect

Civile et al. (2018) suggest that anodal simulation reconfigured the usual processing that creates representations of a stimulus rather than simply reducing recognition performance in general. If it were reducing performance in general then recognition of inverted faces would also be affected. Yet the recognition of inverted faces in Experiments 1 & 2 (Civile et al., 2018) was significantly above chance in the sham and anodal groups and did not differ between groups. Therefore, tDCS appeared to selectively affect performance for upright faces.

In order to explain this effect, Civile et al. (2018) applied the MKM model, able to accommodate the chequerboard results, to the inversion effect with faces. The theory predicted that under standard learning conditions, the elements common to faces (e.g. 2 eyes, a nose, a mouth etc.) are latently inhibited because they appear almost invariably in the faces we see. The unique elements of an individual’s face however, (e.g. the particular spatial distance between the eyes, between the nose and the mouth, a mole on the cheek) will maintain higher salience because they appear less often, are less well predicted by the other features of the face and have weaker connections to the central tendency. In the case of human faces, therefore, repeated exposure over a lifetime leads to an extremely sophisticated ability to distinguish between different individuals. Anecdotally, this process is often also seen in families with twins. Close family members and friends who see the twins often are usually able to tell them apart. However, new acquaintances often struggle until the twins become more familiar to them. The same process happens between perceivers and any face they see in the general population. The same is not true, however, of inverted faces. Our lack of experience with this category of stimuli means that our ability to distinguish between different faces when presented upside down is significantly reduced. Inverted faces produce different patterns of activation than upright faces because the features, though the same, appear in different locations. As such we are comparatively less familiar with the location-specific feature information of an inverted face - we have less expertise. The MKM theory argues that it is this relative difference in expertise which drives the inversion effect.

Applying tDCS, however, appeared to drastically alter this effect. Instead of repeated exposure leading to greater discriminability and the standard inversion effect, tDCS seemed to disrupt this process so that the same associations previously producing low error terms in the prototypical features (which led to low salience) instead boosted their overall activation. This has the effect of increasing the salience of the prototypical features, enhancing generalisation between them, and rendering the familiar stimuli (upright faces) more perceptually similar and harder to distinguish. The inverted faces, however, remain unaffected because, as an ‘unfamiliar’ category of stimuli, the usual perceptual learning effect of enhanced discrimination is not present anyway. In a strikingly similar vein to the chequerboard results from Civile et al. (2016), the inversion effect is reduced by anodal tDCS, specifically by reducing performance for the upright faces, compared to sham.

Testing the hypothesis further; Thatcherised faces.

In order to test the hypothesis further and to strengthen the theoretical analysis offered, Civile et al. (2020) sought a set of circumstances where increasing generalisation using tDCS stimulation could theoretically improve performance on a task rather than reduce it. The authors suggested that an experiment using Thatcherised faces in the '*old/new recognition task'* could be appropriate based on an analysis using the MKM theory of perceptual learning.

Thatcherised faces are a set of manipulated faces where the eyes and mouth have been inverted while the rest of the face remains upright. There are different procedures used to do this where some flip the entire central region of the face and others flip each feature individually. Regardless of the specific method, the result is an image which is still obviously a face, but when presented upright, the inverted eyes and mouth stand out producing an effect which perceivers easily spot (see *Figure 2*). However, upon inversion, the manipulated features are often not easily recognised. This effect is known as the 'Thatcher Illusion' (Thompson, 1980).

Using a location specific account of face processing, the authors predicted that the inverted features in an upright Thatcherised face would become 'super-salient ' compared to the other features of the face because they are wrongly predicted by those other features in the face. This should mean that they come to dominate learning and will promote generalisation between the features of the upright Thatcherised faces, making different individuals very hard to distinguish because they will appear very similar. In contrast, the authors predicted that the inverted Thatcherised faces would not be subject to the same effect because they would be treated as novel stimuli, as are regular inverted faces, meaning all the features would be equally unpredicted. Though the eyes and the mouth would be in the correct or expected orientation (upright eyes and mouth in an inverted Thatcherised face) because their location would not be predicted, this should greatly reduce any effect. For upright Thatcherised faces, the addition of tDCS was predicted to improve performance because removing error-based modulation of salience using tDCS should remove the problem the 'super-salient' features cause in promoting generalisation between the upright faces. As the inverted Thatcherised faces were thought to be left mostly unaffected, the authors predicted anodal stimulation would enhance the inversion effect for Thatcherised faces by improving performance on the upright Thatcherised faces.

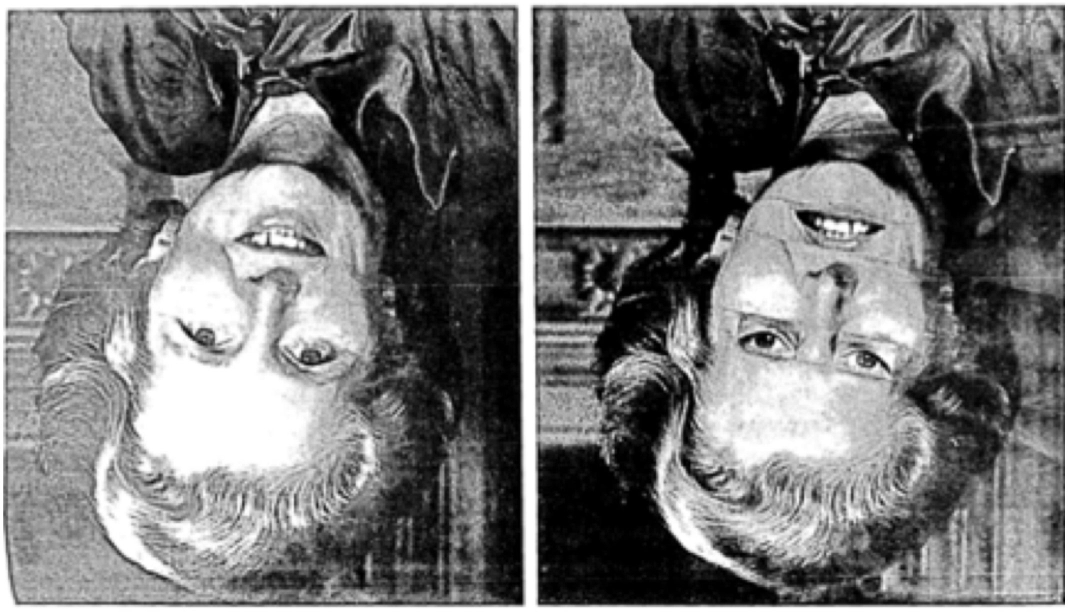

***Figure 2.* The' Thatcher' illusion. The left panel shows an unmanipulated inverted image of Margret Thatcher's face. The right panel shows her manipulated, Thatcherised face. Taken from Thompson (1980).**

Experiment 1 (Civile et al., 2020) used the same '*old/new recognition'* task with regular and Thatcherised faces, both upright and inverted. The results showed the standard inversion effect for regular faces and a reduced but still significant inversion effect in the Thatcherised faces. The reduced inversion effect in the Thatcherised faces was driven by significantly lower performance for upright

Thatcherised faces compared to regular faces whereas the inverted faces of each type showed similar levels of performance. Experiment 2 of the same paper used the same tDCS paradigm adopted in Civile et al. (2016, 2018, 2019) on the '*old/new recognition*' task with regular and Thatcherised faces. The results showed worse performance on the Thatcherised faces compared to the regular faces overall, as in Experiment 1. Furthermore, a significant inversion effect for the Thatcherised faces was found in the anodal group which was absent in sham. However, and most surprisingly, the inversion effect for the regular faces was significantly increased in the anodal group compared to sham; the opposite of the pattern previously established. The larger inversion effect was driven by numerically higher performance for upright faces in the anodal group compared to sham. That the Thatcherised faces seemed to be in some way influencing the regular faces was a novel, unexpected finding and suggested that some generalisation between the stimulus categories might be taking place.

Using Thatcherised faces to reverse the direction of the effect of tDCS on the face inversion effect

Civile et al. (2018, 2019) showed that anodal stimulation reduces the inversion effect for regular faces, largely by reducing performance on the upright faces. However, adding Thatcherised faces in Civile et al. (2020, Experiment 2) appeared to produce the opposite pattern; an enhanced inversion effect in theThatcherised faces themselves and more importantly in the regular faces they were presented with by increasing performance for upright faces. Experiment 3 (Civile et al., 2020) replicated and extended Experiment 2 in order to test, within the same study, whether tDCS could increase or reduce the inversion effect for regular faces simply by changing the stimuli they were presented with. Experiment 3a presented regular male faces alongside regular female faces while Experiment

3b presented regular male faces alongside Thatcherised male faces in the *'old/new recognition task'*. The same tDCS procedure was adopted as in Experiment 2 and the results were averaged over face type in each sub-experiment as the pattern of results for the regular faces and the 'other 'faces (female faces in 3a, 'Thatcherised faces in 3b) did not significantly differ in each sub-experiment (there was a main effect of Thatcherised faces being worse overall, as before). The results for the averaged face types showed a significantly reduced inversion effect in the anodal group of Experiment 3a compared to sham, but a significantly increased inversion effect in the anodal group of Experiment 3b compared to sham. The three-way interaction *Orientation* (upright/inverted), *Experiment* (3a, 3b), *tDCS* (sham/anodal) was also significant; showing a significant difference between the inversion effects in each experiment (*Figure 3)*. As in Experiment 2, the results for the Thatcherised faces alone showed an increased inversion effect in the anodal group compared to sham.

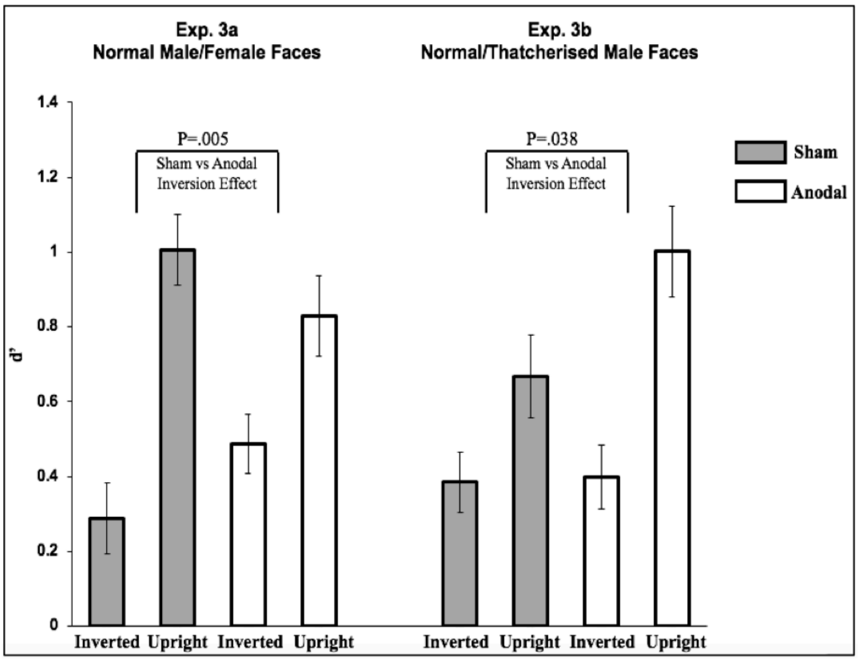

Figure 3. **Graph taken from Experiment 3 of Civile et al. (2020). The graph shows the results for the faces averaged over type in each experiment. Experiment 3a presented regular male faces with regular female faces, Experiment 3b presented regular male faces with Thatcherised male faces.**

Thatcherised faces and generalisation

Experiment 3 succeeded in showing that within the same study, anodal tDCS could selectively increase or reduce the inversion effect for regular faces depending on the stimuli they were presented with. The results from Experiment 3b also suggest that some generalisation from the Thatcherised faces onto the regular faces must have occurred as the inversion effect in the sham group of sub-experiment 3b was numerically smaller than in 3a. In particular, it appeared that the upright faces in the sham group were disproportionately affected in Experiment 3b compared to in 3a. Therefore, the generalisation from Thatcherised faces onto regular faces appeared to be sufficient to reduce performance on the latter. However, the effect did not reach significance which the authors argued might be due to the design of the task in Experiment 3a.

In order to explain why the inversion effect in the sham condition of Experiment 3b was smaller than in 3a, the authors argued that generalisation between the upright Thatcherised and upright regular faces must have occurred because, despite the featural manipulation inherent in Thatcherised faces, both sets of stimuli are faces and consequently share many of the same features. This generalisation reduced '*old/new'* discrimination performance. However, the same would, to some extent, be true of the male and female faces presented together in Experiment 3a. Civile et al., (2020) argue that because the Thatcherised features of the Thatcherised face (the inverted eyes and mouth) are incorrectly predicted by the other facial features, they have become comparatively 'super-salient'. Therefore, the Thatcherised faces attract more learning to these changed features than the regular faces and thus generalisation from this category onto the regular faces happens to a greater extend and is more damaging than that which occurred between male and female faces in Experiment 3a. The analysis offered refers to upright faces specifically, as these are the stimulus category perceivers have expertise with, while the inverted faces are left comparatively unaffected because they are an unfamiliar orientation, i.e. all of the features of the face are equally unpredicted (Civile et al. 2020). In the anodal condition of Experiment 3b, the inversion effect was increased, due to numerically higher performance for the upright faces in the anodal group compared to sham. The authors argued that by disrupting the modulation of feature salience on the basis of error, anodal tDCS freed the upright faces from the deleterious generalisation described above, thus improving their performance and explaining the opposing results in each sub-experiment (Civile et al., 2020).

Extending Civile et al., 2020

The results from the sham condition of Civile et al. (2020) suggested that generalisation from the Thatcherised faces onto regular faces was sufficient to reduce the inversion effect in the latter. That generalisation from a set of manipulated faces could do so was a novel finding in the literature. However, the difference between the inversion effect for regular faces presented with Thatcherised faces to those presented with other ‘normal ’faces did not reach significance in this experiment (Civile et al., 2020). In retrospect, the authors argue that the female faces did not provide the best comparison condition because having so many faces from the same category (regular faces) presented together, despite the gender difference, created a very difficult task. Furthermore, when designing Experiment 3a, the authors assumed that the female faces would be treated as an independent class of stimuli to the regular male faces so that generalisation between the two would be essentially negligible. However, upon reflection, it was suggested that an explicitly independent class of stimuli would likely provide a better control for the effect of ‘Thatcherisation’ seen in sub-experiment 3b as little or no generalisation should occur between the sets of stimuli. In the next chapter, this line of enquiry is pursued with some success in confirming these suggestions.

Chapter 2 : Experiment 1

Experiment 1 establishes that presenting Thatcherised faces alongside regular faces leads to a reduced the inversion effect for those regular faces compared to when regular faces are presented with checkerboards (i.e. stimuli that do not generalise onto regular faces). In Experiment 1a, regular faces are presented alongside Thatcherised faces while in Experiment 1b, regular faces are presented alongside familiar chequerboards. Pursuant to the theoretical analysis given, it was predicted that the inversion effect in the sham tDCS condition would be smaller in Experiment 1a than 1b, due to the negative effect of generalisation from Thatcherised to regular faces. Secondly, it was predicted that the inversion effect for regular faces presented with chequerboards (1b) would be reduced in the anodal group compared to sham whereas the inversion effect would be enhanced in the anodal group compared to sham when the regular faces were presented with Thatcherised faces (1a).

Method

Subjects

128 naïve right-handed participants were recruited from the University of Exeter (40 male, 88 Female; mean age = 20.7 years, age range= 18-29). The sample size was increased from Civile et al. (2020) in order to increase the number of participants in each tDCS group in each sub-experiment which increased the power. Participants completed a safety screening form, approved by the University of Exeter's Research Ethics Committee, before consenting to participate and were offered course credit or payment for their participation. Participants were randomly assigned to tDCS condition (64 anodal, 64 sham) using a double-blind procedure.

Materials

The same facial stimuli were used as in Civile et al. (2020), sourced from Civile et al. (2011). The faces displayed neutral expressions in grayscale on black backgrounds. They were standardised using Adobe Photoshop, such that the ears and hair were cropped and any distinguishing features (e.g. facial piercings) were removed. For Experiment 1a, four categories of facial stimuli were created: regular female upright, regular female inverted, Thatcherised female upright, Thatcherised female inverted. The Thatcherised faces were the sourced from Civile et al. (2020) and had been manipulated by inverting each eye and mouth individually. The faces were counterbalanced so that each face appeared once in each of the four stimulus conditions and so that each face was seen in each of the stimulus conditions across the eight participant groups. For Experiment 1b, the same regular female upright and inverted faces were used and sets of 16 x 16 chequerboards (each cell 16 x 16 pixels) were created using MatLab to be presented alongside them. Four prototype-defined categories of chequerboards were created, from which different exemplars were made by randomly selecting 96 squares and changing 48 cells on average in each exemplar to give variations of the base pattern. The chequerboards were also presented in grayscale on a black background. The stimuli were presented at a resolution of 1280 x 960 pixels, sized at 5.5cm x 5.5cm. Participants sat approximately 70cm from the screen and the experiments were run on an iMac computer using Superlab 4.07b.

tDCS Procedure

The same tDCS procedure used in Civile et al. (2020), adapted from Ambrus et al. (2011) and used by Civile et al., (2016, 2018, 2019) was adopted for this study (*Figure 4)*. The neuroConn tCDS system was used to deliver the stimulation in this study. The neuroConn system is a battery-driven device delivering stimulation to the scalp via a pair of surface electrodes (35 cm^2) soaked in saline solution. A bilateral bipolar unbalanced montage was adopted meaning the active and reference electrodes were placed in difference places, on opposite sides of the head and stimulation was delivered using a current which had two poles rather than one. The active electrode was placed over the left Dorsolateral Prefrontal Cortex at site Fp3, and the reference electrode was placed over the right forehead above the eyebrow.

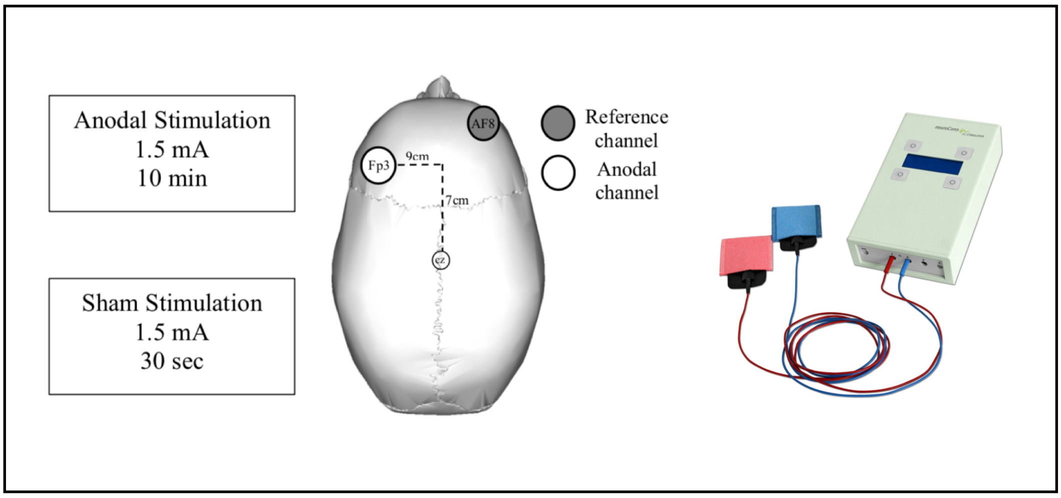

***Figure 4.* A schematic representation of the tDCS montage used in Experiment 1, 2 and 3. Adapted from Ambrus et al. (2011), the same montage used in Civile et al. (2016, 2018, 2019, 2020).**

A measuring tape was used to locate Fp3 on each participant by measuring the distance between the bridge of the nose and the external occipital protuberance and halving this number to find cz. From cz, 7cm was measured directly forward keeping in line with the midline, and then 9cm at a right angle was measured down the left-hand side of the head. The electrodes were held in place using rubber straps which went around the base of the head. After the tDCS had been set up and participants were comfortable, the impedance was checked to ensure an acceptable connection had been made between the electrodes and the scalp. The impedance was monitored throughout the study to ensure the stimulation was being effectively delivered. In Experiment 1a, stimulation began at the beginning of the 'study phase 'and ran for 10 minutes. The start of the 'recognition' phase was delayed until the stimulation had ended. In Experiment 1b, stimulation began at the beginning of the 'categorisation phase' and ran for 10 minutes, ending during the 'study phase'. The 'recognition phase' followed immediately after the 'study phase'. In both experiments, the tDCS was left in place until the end of the 'old/new recognition' task to avoid unnecessary disturbance to the participants. The procedure was double-blind, achieved by an independent researcher creating a set of codes corresponding to the two tDCS conditions which were then entered into the neuroConn box to control the stimulation. This procedure ensured neither the researcher nor participant knew whether the stimulation was sham or anodal. In the anodal condition, participants received 1.5 mA of stimulation for 10 minutes, with a 5s fade-in/fade-out. In the sham condition, participants received the same 5s fade-in/fade-out and a totality of 30s stimulation across the 10 minute period delivered in pulses. This gave participants the sensation of being stimulated but without causing any significant changes in cortical excitability (Woods net al., 2016). The pulses ensured impedance remained acceptably low throughout the experiment. At the end of the experiment, the tDCS equipment was removed and participants completed a safety screening form before being debriefed. For safety reasons, two researchers were in the lab while the experiment was running, and both had received first aid training prior to testing.

Study Procedure

In Experiment 1a, participants completed an old/new recognition task comprising a 'study' phase and 'old/new recognition' phase (*Figure 5*). During the 'study 'phase, anodal tDCS started in the experimental group and participants were asked to memorise the faces presented. 64 were presented in total; 16 of each type (regular upright, regular inverted, Thatcherised upright, Thatcherised inverted), one at a time in a random order. A fixation cross appeared for 1000ms before each face, after which the faces were presented and remained on the screen for 4000ms during which no response was required. During the 'recognition' phase, 128 faces were presented in total; these comprised the 64 'old' faces (those seen in the study phase) and 64 'new' (previously unseen split by the same conditions). The faces were again presented one at a time in a random order. Participants were instructed to respond to the faces using the keyboard to indicate whether they thought they had seen that face before. Trials began with a 1000ms fixation cross followed by the stimuli, presented for 4000ms, during which time participants responded or the trial timed out with the message 'Too slow'. The response keys were counterbalanced across conditions such that half of the participants pressed 'x' to indicate they had seen the face before (old) , and '.' to indicate that they had not (new). The other half responded in the opposite manner.

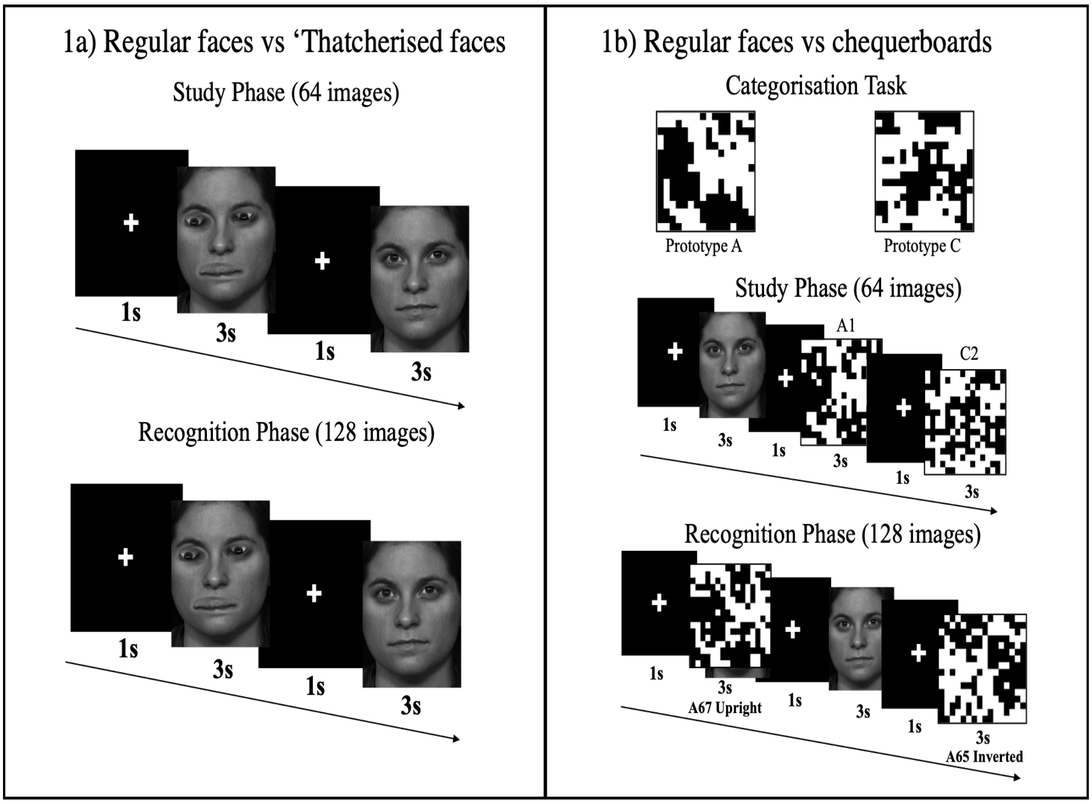

Figure 5. **A schematic representation of the '*old/new recognition*' task used in Experiment 1a and 1b.**

In Experiment 1b, participants completed an additional categorisation task, before the ‘study’ phase, in order to familiarise them with two sets of prototype-defined chequerboards. During the categorisation phase, participants were shown 128 exemplars from two categories of prototype defined chequerboards (64 from each category) which they learnt to categorise, initially by trial and error, on the basis of the feedback they received. Participants then moved onto the ‘study’ phase, during which they were shown 64 images; 32 regular upright and inverted female faces (16 of each type) and 32 exemplar chequerboards (16 upright, 16 inverted). The chequerboards were different exemplars shown in the ‘categorisation’ phase but drawn from one of the familiarised categories. In the ‘recognition’ phase, participants were shown 128 images; the same 32 regular upright and inverted female faces and 32 exemplar chequerboards seen in the study phase, intermixed with 32 new upright and inverted faces and 32 new chequerboards exemplars drawn from the same familiarised category. The two sub-experiments were run in parallel.

Results

Behavioural Data Analysis

Following the analysis conducted by Civile et al. (2014, 2016, 2018, 2019, 2020); performance accuracy in the ‘recognition’ phase of the ‘old/new recognition’ task was converted into a d-prime (d’) sensitivity measure according to the procedure outlined in Stanislaw & Todorov (1999). d’ is a measure of performance accuracy independent of response bias. d’ scores were calculated for each participant for each of the four stimulus conditions by subtracting each participant’s transformed false alarm (F) rate (the proportion of NO trials the participant responded YES to) from their transformed hit (H) rate (the proportion of YES trials participants responded YES to). The equation used to calculate d’ was: d' = z(H) - z(F) where the difference between the z-transformations of H and F were used to calculate d’ rather than simply H-F. A d’=0 indicates 50% accuracy or chance-level performance and as the best performance would maximise H and minimise F, the larger the difference between the two, the greater the participant’s sensitivity. Performance for all the face types was also assessed against chance using paired-value t tests. These showed that in Experiment 1a, both the regular and Thatcherised faces were recognised significantly above chance ($p=<.005$) in both orientations and tDCS groups. In Experiment 1b, the regular faces were recognised significantly above chance in the sham and anodal tDCS groups ($p=<.005$). However, only the upright chequerboards in the anodal group were recognised significantly about chance ($p=.004$). F or t values are reported along with a measure of effect size (η^2_p) and p-values, which are two-tailed unless otherwise stated.

As the regular faces are of primary interest in this experiment, the main analysis is the three-way interaction from the main 2x2x2 ANOVA using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factors *Experiment* (1a/1b) and *tDCS Condition* (sham/anodal) conducted on the results for the regular faces only. The three-way interaction is then broken down by tDCS condition first sham, then anodal; in order to examine any differences between the experiments. In the next analysis, the main 3-way interaction is broken down by experiment 1a then 1b, in order to examine the differences between the inversion effects in the sham and anodal conditions of each experiment. The results for the Thatcherised faces and chequerboards are also analysed. Performance for the Thatcherised faces was compared against the regular faces before a 2x2 repeated measures mixed model ANOVA (*Orientation x tDCS)* was used to examine the effect of tDCS on the Thatcherised faces. The same 2x2 ANOVA was run for the chequerboards. Finally, the results from experiment 1a were combined with Civile et al., 2020 Experiment 2 and 3b, and another tDCS and EEG study currently in press. The combined results were then re-analysed such that the main 2x2x4 ANOVA for the regular faces using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (2, 3b, 1a, tDCS*EEG) was re-run and again decomposed by tDCS condition. The same 2x2x4 ANOVA was then run for the Thatcherised faces and also decomposed by tDCS condition. F values are reported along with a measure of effect size (η^2_p) and *p*-values, which are two-tailed unless otherwise stated. Additional statistics can be found in appendix 1.

Analysis for the regular faces between Experiment 1a and 1b

The primary 2 x 2 x 2 ANOVA was calculated using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factors *Experiment* (1a/1b) and *tDCS Stimulation* (sham/anodal). The main effect of the within-subject factor *Orientation,* $F(1,124)= 104.112$, $p<.001$, $\eta^2_p=.456$ was significant, reflecting better performance for upright than inverted faces. The main effect of the between-subject factors *Experiment* was also significant, $F(1,124)= 7.346$, $p=.008$, $\eta^2_p=.056$ however the main effect of *tDCS* was not significant, $F(1,124)= 1.260$, $p=.264$, $\eta^2_p=.01$ as expected, which demonstrates that tDCS did not affect performance overall. The interaction *Orientation* x *tDCS,* $F(1,124)= 4.604$, $p=.034$, $\eta^2_p=.036$ was also significant however the interaction *Orientation* x *Experiment*, $F(1,124)= .260$, $p=.611$, $\eta^2_p=.002$ was not. The critical three-way interaction, $F(1,124)= 12.306$, $p=.001$, $\eta^2_p=.09$ was significant; reflecting the expected pattern of results in each sub experiment (*figure 6*). This pattern of results will now be described in more detail.

Analysis for the regular faces in the sham condition.

A 2x2 repeated measures mixed model ANOVA examining the inversion effect for the within-subjects factor *Orientation* in the sham groups of *Experiment* 1a and 1b revealed a significant main effect of *Orientation,* $F(1,62)=73.081$, $p<.001$, $\eta^2_p=.541$ and a significant two-way interaction between the experiments, $F(1,62)=4.306$, $p=.042$, $\eta^2_p=.065$. To further examine the difference in the inversion effects between experiments indicated by this significant interaction, a simple comparison analysis was carried out. A paired *t* test for the sham group of Experiment 1a revealed a significant inversion effect in *Experiment,* 1a, $t(31)=5.589$, $p<.001$, $\eta^2_p=.502$ (Upright faces mean 1.26; SD .629, Inverted faces mean = .588; SD .646) and in Experiment 1b, $t(31)=6.516$, $p<.001$, $\eta^2_p=.578$ (Upright faces mean 1.738; SD .948, Inverted faces mean .635; SD .486). The unpaired *t* test examining the difference between upright faces in the sham conditions of Experiment 1a and 1b revealed upright regular faces were significantly better recognised in *Experiment* 1b, $t(62)=2.52$, $p=.014$, $\eta^2_p=.093$. Thus, the significant interaction is due to the inversion effect being larger in Experiment 1b, and this is due to upright faces being better recognised in that experiment.

Analysis for the regular faces in the anodal condition.

A 2x2 repeated measures mixed model ANOVA using the within-subjects factor *Orientation* for participants in the anodal groups of Experiment 1a and 1b revealed a significant main effect of *Orientation,* $F(1,62)=3.937$, $p<.001$, η^2_p

=.354 and a significant two-way interaction between *Experiment* and *Orientation,* $F(1,62)=8.439$, $p=.005$, $\eta^2_p=.12$. The paired *t* test for the anodal group of Experiment 1a revealed a significant inversion effect, $t(31)=6.932$, $p<.001$, $\eta^2_p=.608$ (Upright faces mean 1.213; SD.602. Inverted faces mean .345; SD .47) which was not found in Experiment 1b, $t(31)=1.88$, $p=.07$, $\eta^2_p=.102$ (Upright faces mean 1.238; SD .998. Inverted faces mean .947; SD .875). A follow-up unpaired *t* test revealed upright faces were not recognised significantly differently between the anodal groups of Experiment 1a and 1b, $t(62)=.118$, $p=.906$, $\eta^2_p<.001$. The significant interaction is due to the significant inversion effect in Experiment 1a though, unlike in the sham group, the difference between recognition of upright faces was not significant and did not seem to drive the effect.

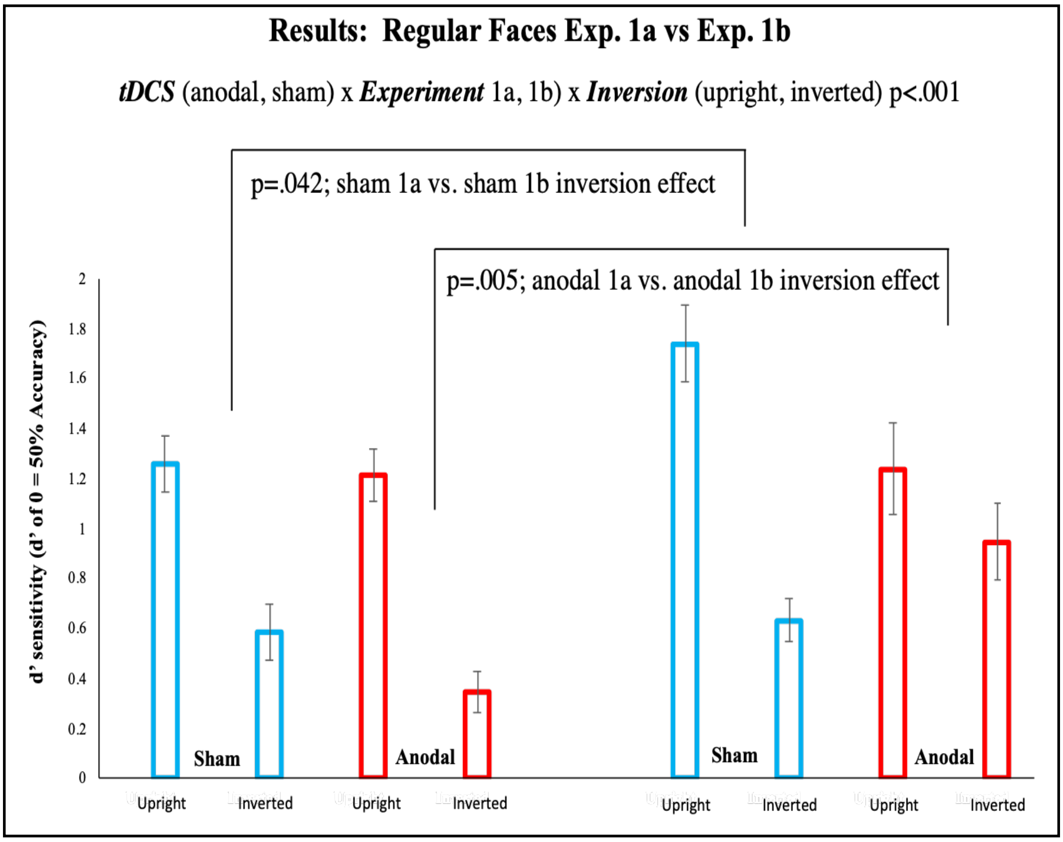

Figure 6. Graph to show the results for the regular faces from Experiment 1. The x-axis shows the stimulus conditions for each tDCS group. The y-axis shows *d'*. Error bars represent s.e.m.

Additional Analysis

Analysis for the regular faces in Experiment 1a

A 2x2 ANOVA on the regular faces in Experiment 1a using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factor *tDCS* (anodal/sham) revealed a main effect of *Orientation,* $F(1,62)=78.692$, $p<.001$, $\eta^2_p=.559$ with upright faces being better recognised than inverted faces, and a non-significant two-way interaction, $F(1,62)=1.272$, $p=.264$, $\eta^2_p=.02$. This indicated no significant differences between the inversion effect in the sham and anodal conditions of Experiment 1a which was somewhat unexpected and will be returned to later in the discussion.

Analysis for the Thatcherised Faces in Experiment 1a

A 2x2 repeated measures mixed model ANOVA examining the inversion effect for the within-subjects factor *Orientation* for participants in the sham and anodal groups revealed a significant main effect of *Orientation,* $F(1,62)=5.568$, $p=.021$, $\eta^2_p=.082$ but a non-significant two-way interaction between the tDCS groups, $F(1,62)=.883$, $p=.351$, $\eta^2_p=.014$. This showed that tDCS had no significant effect on the Thatcherised faces themselves. Finally, for correctness the mean average and standard deviation for the Thatcherised faces in each stimulus and tDCS condition are reported. Upright Thatcherised faces in sham; mean .629, SD .481. Inverted Thatcherised faces in sham; mean .502, SD .675. Upright Thatcherised faces in the anodal condition; mean .634, SD .611, inverted Thatcherised faces in the anodal condition mean .339, SD .519.

Analysis for the regular faces in Experiment 1b

A 2x2 ANOVA examining the within-subjects factor *Orientation* (up/inverted) and the between-subjects factor *tDCS* (anodal/sham) revealed a significant main effect of *Orientation,* $F(1,62)=36.972$, $p<.001$, $\eta^2_p=.374$ and a significant two-way interaction, $F(1,62)=12.577$, $p=.001$, $\eta^2_p=.169$ which demonstrated a significantly smaller inversion effect in the anodal condition compared to sham. As expected, this reflects the standard effect of tDCS on the face inversion effect (see Civile et al., 2018, 2019, 2020 experiment 3a) which is a reduced inversion effect in the anodal group compared to sham.

Analysis for the chequerboards in Experiment 1b

A 2x2 repeated measures mixed model ANOVA examining the inversion effect for the within-subjects factor *Orientation* for participants in the sham and anodal groups revealed no significant main effect of *Orientation,* $F(1,62)=.155$, $p=.695$, $\eta^2_p=.002$ and a non-significant two-way interaction between the tDCS groups, $F(1,62)=1.111$, $p=.296$, $\eta^2_p=.018$. This showed, as with the Thatcherised faces, that tDCS had no significant effect on the chequerboards themselves. Finally, for correctness the mean average and standard deviation for the chequerboards in each stimulus and tDCS condition are reported. Upright chequerboards in sham; mean .044, SD .516. Inverted chequerboards in sham; mean .098, SD .437. Upright chequerboards in the anodal condition; mean .276, SD .472, inverted chequerboards in the anodal condition mean .158, SD .526.

Combined results from Experiment 1a and Civile et al. 20203b.

Regular Faces

To investigate why the 2x2 ANOVA examining the inversion effect for the regular faces between the sham and anodal conditions of Experiment 1a was not significant, the results from Experiment 1a were combined with the previous results obtained by the lab for experiments testing regular and Thatcherised faces together. Accordingly, Experiments 2 and 3b from Civile et al. 2020 and another tDCS and EEG study were considered with the results from Experiment 1a of this study. The main 2 x 2 x 4 ANOVA for the regular faces was re-run using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (Civile et al. 2020 Experiment 2/Civile et al. 2020 Experiment 3b/Experiment 1a/tDCS*EEG experiment). The main effect of *Orientation* was significant, $F(1,272)=191.374$, $p<.001$, $\eta^2_p=.413$ confirming upright faces were better recognised than inverted faces. The two-way interaction *Orientation* by *tDCS* was also significant, $F(1,272)=12.646$, $p<.001$, $\eta^2_p=.044$ however the interaction *Orientation* by *Experiment,* $F(1,272)=.453$, $p=.716$, $\eta^2_p=.005$ was not. Critically, the three-way interaction was not significant, $F(1,272)=.520$, $p=.669$, $\eta^2_p=.006$, indicating there were no significant differences between the experiments and supporting the data being combined and reanalysed. Accordingly, the 2x2 repeated measures mixed model ANOVA for the regular faces examining the inversion effect for the within-subjects factor *Orientation* and the between-subjects factor *tDCS* (sham/anodal) revealed a significant main effect of *Orientation,* $F(1,278)=204.888$, $p<.001$, $\eta^2_p=.424$, a non-significant main effect of tDCS, $F(1,278)=.298$, $p=.586$, $\eta^2_p=.001$ and a significant two-way interaction, $F(1,278)=15.131$, $p<.001$, $\eta^2_p=.052$ showing that the inversion effect between the sham and anodal conditions significantly differed, being greater in the anodal condition. The paired *t* test examining the inversion effect for regular faces showed that the upright faces were recognised significantly better than the inverted faces in the sham, $t(139)=7.743$, $p<.001$, $\eta^2_p=.302$ (Upright faces mean .983; SD .736. Inverted faces mean .492; SD .671) and anodal conditions, $t(139)=12.283$, $p<.001$, $\eta^2_p=.521$ (Upright faces mean 1.203; SD .717. Inverted faces mean .344; SD

=.584). A between-subjects *t* test comparing upright faces in the sham and anodal conditions revealed that anodal stimulation significantly improved recognition of the upright faces compared to sham under these circumstances, t(278)=2.528, *p*=.012, η^2p=.022. Therefore, across all of the experiments conducted by the lab involving regular and Thatcherised faces, anodal stimulation did significantly increase the inversion effect for regular faces presented with Thatcherised faces compared to sham (*figure 7*).

Thatcherised Faces

The same combined analysis was run for the Thatcherised faces alone. The 2 x 2 x 4 ANOVA for the Thatcherised faces was re-run using the within-subjects factor *Orientation* (upright/inverted) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (Civile et al. 2020 Experiment 2/Civile et al. 2020 Experiment 3b/Experiment 1a/tDCS*EEG experiment). The main effect of *Orientation* was significant, F(1,272)=14.422, *p*<.001, η^2p=.05 confirmed upright faces were better recognised than inverted faces. The two-way interaction *Orientation* by *tDCS* was not significant, F(1,272)=2.426, *p*=.12, η^2p=.009 and neither was the interaction *Orientation* by *Experiment,* F(1,272)=1.415, *p*=.239, η^2p=.015. Critically, the three-way interaction was not significant either, F(1,272)=.761, *p*=.517, η^2p=.008, indicating the studies did not interact with effects of tDCS on the inversion effect which supported the data being reanalyzed in this way.

Accordingly, the 2x2 repeated measures mixed model ANOVA examining the inversion effect for the within-subjects factor *Orientation* and the between-subjects factor *tDCS* (sham/anodal) revealed a significant main effect of

Orientation, $F(1,278)=15.028$, $p<.001$, $\eta^2_p=051$ a non-significant main effect of *tDCS*, $F(1,278)=.014$, $p=.905$, $\eta^2_p<.001$ and a still non-significant two-way interaction, $F(1,278)=1.944$, $p=.164$, $\eta^2_p=.007$. This demonstrates a possible weak effect of tDCS on the Thatcherised faces across these experiments, but one which is not comparable to that of the regular faces.

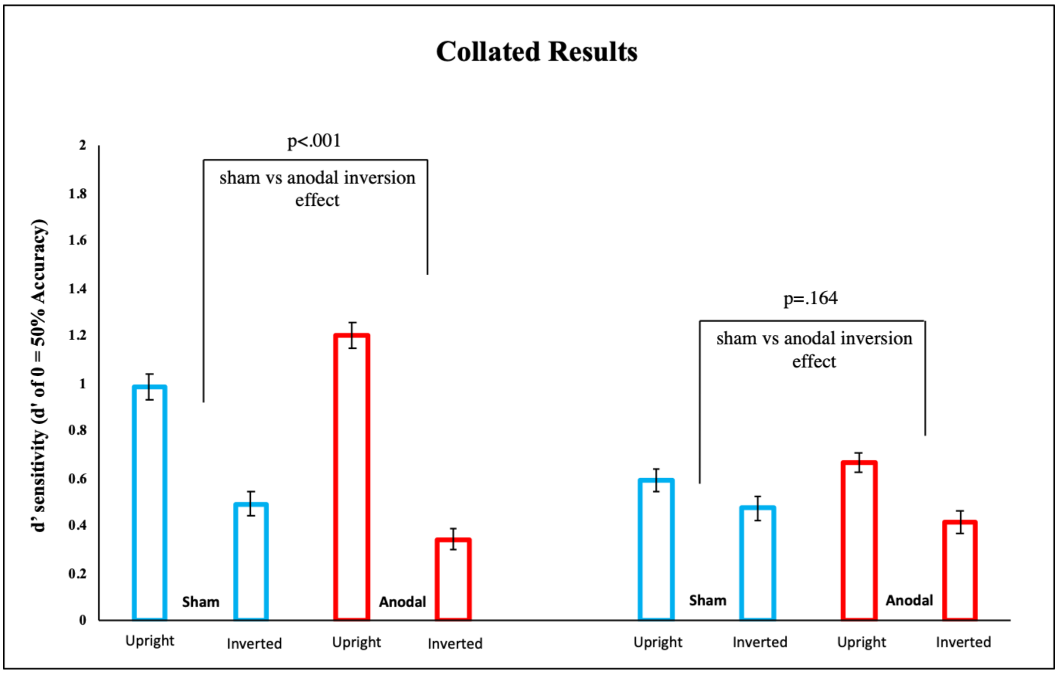

***Figure 7.* Graph to show the collated results for regular and Thatcherised faces from Civile et al. (2020) Experiment 2 and 3b, the tDCS*EEG study in press and Experiment 1a of this paper. The x-axis shows the stimulus conditions for each tDCS group. The y-axis shows *d'*. Error bars represent s.e.m.**

Discussion

Experiment 1 has demonstrated that in sham, a set of manipulated faces, Thatcherised faces, generalise onto regular faces sufficiently to significantly reduce the inversion effect for regular faces. As can be seen in *figure 6,* the inversion effect for regular faces is larger in the sham condition of Experiment 1b, where regular faces were presented with chequerboards, than Experiment 1a where they were presented with Thatcherised faces. The effect was mainly driven by the better recognition of upright faces in Experiment 1b. Experiment 1 also succeeded in replicating the pattern of results seen in the two sub-experiments of Civile et al. (2020) Experiment 3; namely the smaller inversion effect for regular faces presented with Thatcherised faces compared to when they are presented with comparison stimuli can be reversed with anodal stimulation. In the anodal groups, the inversion effect was significantly larger in Experiment 1a than 1b, with the inversion effect in the latter not reaching significance and no difference between the upright faces in each experiment. This finding supports the theoretical conclusion that tDCS disrupts error-based feature salience modulation and enhances generalisation between stimuli within a familiar category.

Somewhat unexpectedly, there was no significant difference between the inversion effect for regular faces in the sham and anodal conditions of Experiment 1a. Though, as expected on the basis of previous studies, there was a significantly reduced inversion effect in the anodal group of Experiment 1b compared to sham. On the basis of Civile et al. (2020) it was expected that a significantly increased inversion effect for regular faces would be found in the anodal group of Experiment 1a as the effect of tDCS has been characterised as freeing the regular faces from the unhelpful generalisation occurring from Thatcherised faces. Discussion as to why this effect might not have reached significance is reserved for the general discussion. Though it is important to note that a significant difference between the inversion effects for regular faces did appear in the combined results between the sham and anodal groups. Specifically, this was driven by the significantly better recognition of upright faces in the anodal group compared to sham as predicted on the basis of an MKM-based theoretical analysis.

Also unexpectedly, there was no significant inversion effect for the chequerboards in the sham condition of Experiment 1b, and no significant effect of tDCS. On the basis of previous studies (see Civile et al., 2016) this was surprising. However, towards the end of the study a failure in the counterbalancing was discovered with the chequerboard stimuli which was fixed, but only for the final participants. There may also have been an effect of tDCS timing, discussion of which is reserved for the general discussion.

Overall, this experiment has succeeded in demonstrating that Thatcherised faces generalise onto regular faces sufficiently to reduce the inversion effect on the latter. Additionally, using anodal tDCS makes it is possible to selectively increase or reduce the inversion effect for regular faces simply by changing the stimuli those regular faces are presented with. Chapters 2 and 3 present the results from a second and third experiment examining the effect of the same neurostimulation procedure in a different experimental task.

Chapter 3 : Experiments 2 & 3

Experiment 1 established the effect of tDCS on the *'old/new recognition'* task with faces. Characterised in terms of the MKM model, the analysis of Experiment 1 suggested tDCS effectively abolished error-based feature salience modulation which facilitated *'old/new recognition'* judgements in sham. In the situation where regular faces were presented with checkerboards, the effect of tDCS was to increase generalisation between the common elements of familiar stimuli and the results were in line with Civile et al. (2018, 2019, 2020) who found the same effect of anodal stimulation on the face inversion effect and Civile et al. (2016) on the inversion effect with chequerboards. In the situation where regular faces were presented with Thatcherised faces, where sham performance on regular faces was depressed, the effect of anodal stimulation was to abolish the unhelpful generalisation from Thatcherised to regular faces which consequently improved performance. Importantly, the abolition of error-based modulation could have the effect of either increasing generalisation or disrupting unhelpful generalisation between familiar stimuli. Having established the effect of this tDCS paradigm on the '*old/new recognition* 'task, Experiments 2 and 3 investigated the effect of the same tDCS paradigm on a different experimental task; one which perceivers might be more likely to encounter in 'real life'.

Visual search tasks are a common, though not usually high-risk, aspect of everyday life. Whether it is searching for a particular ingredient on a food label or a partner in a supermarket, the average person is surprisingly adept at performing this kind of task. However, some occupations require more complex visual searches where failure can have severe consequences. For example, the radiographer whose job it is to find a malignant tumor among the multitude of x-ray images they see every day. Similarly, in the world of security, visual searches are of great importance and are still often carried out by personnel rather than computers. One example is the detection of target individuals, for example terrorists, in images of crowds. Analysts try to spot individuals with whom they have been familiarised by responding on a keyboard to indicate target 'present' or 'absent' in the images they see. This kind of complex visual search is extremely difficult, most especially when combined with the attempted recognition of unfamiliar faces which is another particularly difficult task (Hancock, Bruce & Burton, 2000).

To continue the comparison between faces and chequerboards, the target detection study was run in two replications; the first with faces and the second with familiar chequerboards. Previous studies have shown that presenting two stimuli in immediate succession without delay makes it very easy to detect a change between the stimuli; a phenomenon known as the 'Phillips Effect' (Phillips, 1974). Further to this, the 'Rensink Effect' refers to the fact that change detection becomes harder if a mask is presented between two stimuli (Rensink et al., 1997). At the time, it was suggested that retinal transients were responsible for change detection, however, this explanation suggests that stimulus familiarity has no effect (Suret & McLaren, 2001). Consequently, Suret & McLaren (2001) investigated the effect of familiarity on the Rensink effect. In this experiment, participants were split into two groups with different sets of stimuli. The familiar group were shown the same chequerboard, unique to each participant, on every trial and the random group were shown different chequerboards on every trial. Participants were shown two alternating chequerboards which were either the same or different by one square. Participants responded using the keyboard to indicate whether they thought a 'change' or 'no change' had occurred. The results showed that change detection was significantly better in the familiar group compared to the random group.

Interestingly, participants in the familiar group reported a change in their strategy across the trial period. While those in the random group reported using a serial search to detect the target, as the trials progressed those in the familiar group began to subdivide the stimulus into sections they then scanned for changes. Overall, the results showed that familiarity with a stimulus facilitated change detection. This led the authors to speculate that while serial scanning was used in to detect change on the familiar background, and that this improved over trials, there was also an effect of novelty which led to enhanced discrimination. The novelty effect can also be characterised as the change being salient against the familiar background (Suret & McLaren, 2001).

The MKM model, therefore, can provide an account of why change detection is facilitated on familiar backgrounds. If the elements of the familiar background are considered to be well predicted by the others present, and therefore to possess low salience, then the presence of a target will be novel and relatively higher in salience. The presence of a target on a random chequerboard, however, will not confer the same advantage because the elements of the background will be equally unpredicted whether the target is present of not. Therefore, a change, i.e. the target, will not have higher relative salience from the background and a serial search of the image would be needed to locate it. According to the MKM model, it is the relative salience of the target and the background which facilitates this change detection, or not. And the relative salience difference in this model is brought about by error-based modulation of salience.

In Experiment 1, anodal stimulation was characterised as disrupting error-based salience modulation. Thus the logic follows that if it were to do so in this new detection task, the advantage for change detection conferred by the familiar background might be altered in some way, likely reduced, compared to the random background. Or, the disadvantage for the random background might be mitigated. Thus the logic in applying anodal stimulation to a similar task investigating the effect of background familiarity on target detection was to test the perceptual learning explanation of Suret and McLaren's findings. Yet also with a view to applied research, it was interesting to consider what effect tDCS might have on the security analysts's role described above. One of the aspects of that detection task which makes the analysts role so difficult is the unfamiliarity with the background which changes between every image. By applying the logic from Experiment 1 to the detection of a target in a camouflaged visual search, it was expected that target detection in sham, where standard perceptual learning applies, should be easier on the familiar background. While in the familiar group it is the background that would be common across trials, in the random group, it would be the target which would be common across trials. Therefore, the increased generalisation created by anodal stimulation might facilitate detection on the random background by causing the target (individual or shape) to 'pop-out', or simply remove the advantage the familiar background conferred. However, if anodal stimulation is considered to increase generalisation between the common elements of a class of stimuli, we might expect that the advantage for target detection on the familiar background would be lost as increasing generalisation between the common elements (the background) would reduce discriminability. Whereas in the case of the random background condition, the target is the common element across trials, therefore tDCS might be considered to enhance detection across trials.

Experiment 1, however, also found that in disrupting feature salience modulation tDCS can also have the effect of abolishing generalisation between familiar stimuli. Therefore, applying this logic to the detection task, a subtly different theoretical prediction might be reached. If a target face or shape were to appear on a random background (i.e. a crowd), generalisation from faces or units in the background to the target would likely make detection harder. This generalisation is likely to be greater from a random than a familiar background because the salience of the individuals or units in the familiar background would be lower given they would be well predicted by the other elements present and will have been familiarised over multiple presentations. Therefore, unhelpful generalisation from the random background to the target might be expected to reduce performance in this condition. Reducing or removing this unhelpful generalisation using anodal stimulation could, therefore, be considered to increase performance by making the target easier to detect.

Using a visual search task where a target individual or shape is sought, Experiments 2 and 3 investigated whether tDCS could be used to enhance cognitive performance in the detection task in a way considered to be analogous to the *'old/new recognition'* task. Experiment 2 presented facial stimuli in the detection task and Experiment 3 presented chequerboards so that full experimental control could be exerted over participants familiarity with the stimuli. Experiment 3 also enabled comparisons to be made between the face and chequerboard experiments which it was hoped would shed light on the mechanisms involved in target detection in this task.

Experiment 2

In Experiment 2, two types of facial arrays were presented. The first was a fixed set of 9 faces where a target individual was present or absent on each trial. In this fixed array, the same 9 individuals appeared in the same position in the array on every trial. The second type was an array of 9 randomly selected faces where again the target individual (the same individual across trials for each participant) could be either present or absent on each trial. Two sub-experiments were conducted in parallel where one used the same standardised face stimuli as Experiment 1 and the second used more 'realistic' faces. The two face types were used in Experiment 2 to investigate whether tDCS would have an effect on stimuli encountered in real life as well as on the images used in the lab which are highly standardised. However, as there is very little experimental control over local featural information in the realistic faces, this raised the possibility that the size of the tDCS-induced effects might be quite small. The standardised faces were used as a comparison condition where the expected magnitude of any effects was expected to be larger due to their comparative lack of 'noise'. As such, Experiment 2a presented standardised faces and Experiment 2b realistic faces in the detection task. In the sham tDCS conditions, target detection was expected to be harder, resulting in lower performance, in the random background condition compared to the familiar condition. In the anodal tDCS group, the advantage conferred by familiarity was expected to be reduced or removed as would be expected if perceptual learning had been disrupted.

Method

Subjects

64 naïve participants were recruited from the University of Exeter. Participants completed a safety screening form, approved by the University of Exeter's Research Ethics Committee, before consenting to participate. Participants were offered course credit or payment for their participation. After completing the screening forms, participants were randomly assigned to the order in which they did each sub-experiment (2a/2b), to the participant group (1-16) which determined which target individual they searched for, and to sham or anodal tDCS conditions (32 sham, 32 anodal). The procedure was double-blinded.

Materials

In Experiment 2a, participants saw standardised faces in the detection task. The standardised faces were the same as those used in Civile et al. (2020), sourced from Civile et al. (2011). 338 standardised faces were used in total. A random number generator was used to select specific files which were then allocated to being target faces, faces for the instruction trial or faces for the background arrays. As such, 16 faces were selected to be the targets (8 male, 8 female). 25 faces in total were selected for the instruction array (16 targets; 8 male, 8 female and 9 for the array; 5 male, 4 female). For the experimental arrays, 9 faces (4 male, 5 female) were selected for the fixed array and 288 (144 male, 144 female) were selected for the random arrays. The faces only appeared once in one of the stimulus lists and each participant group searched for one of the 16 target individuals. The faces were presented in grayscale on a black background.

In the fixed background array, the same 9 faces appeared in the same position on every trial. Using Superlab 4.07b, the coordinates of each position in the array were coded which determined where each face appeared on the screen. In the fixed, target present trials, the target would appear 'over the top of' one of the faces in the fixed array, thus replacing one of the 9 fixed background faces. This ensured so that only 9 faces were ever shown at one time. In the random background condition, a different set of 9 background faces appeared on every trial, and again the target could be present or absent and appeared in one of the 9 positions (*figure 8)*. The faces for the 9 positions in the random backgrounds were randomly selected from 9 corresponding stimulus lists created in Superlab. In total participants completed 64 trials in each sub-experiment where 32 were fixed background trials (16 target present, 16 target absent) and 32 were random background trials (16 target present, 16 target absent).

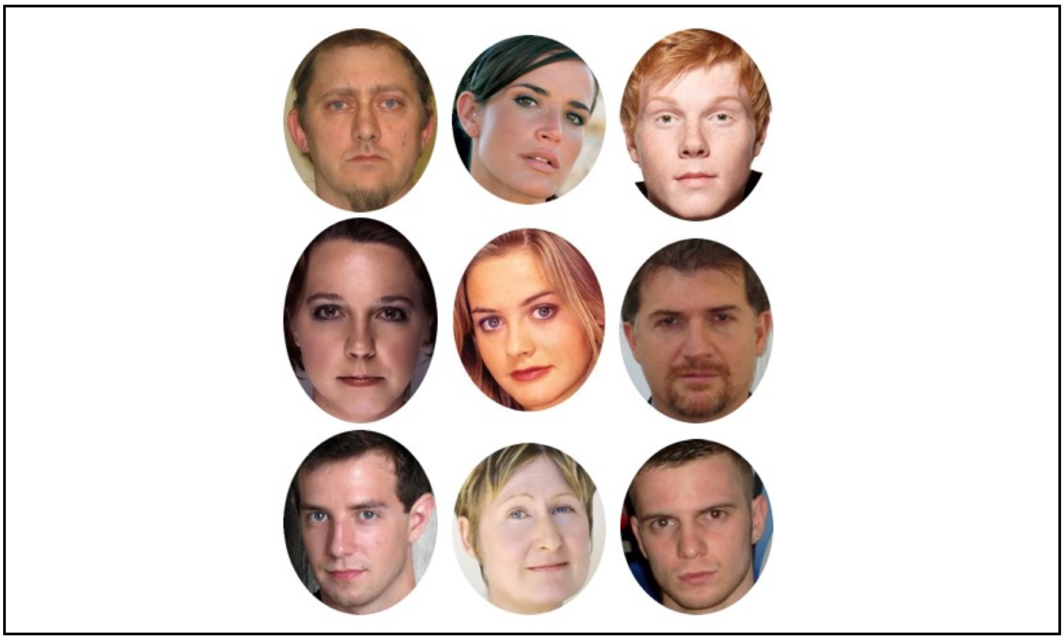

Figure 8. **Example of a practice array used in Experiment 2b. In this trial, the target is present in the central location of the array (position 5).**

In Experiment 2b, the 'realistic' faces were taken from the 10k US adult face database; a collection of natural face photographs where each face has a corresponding memorability score, attribute ranking, and demographic information. The faces in the 10k database were designed to align with the 1990 US census (Bainbridge, Isola, Oliva, 2013). Images of celebrities were removed in order to maximise control over participants' familiarity with the faces and all individuals under the age of 18 or over 70 were excluded. The 18-69 age-range was chosen so that the realistic face experiment would be comparable to the standardised ones, and to avoid having individuals who would stand out from the main sample because of their age (*figure 9)*. As with the Standardised faces experiment, only Caucasian faces were used in the arrays. From the remaining faces, a random number generator was used to select 338 faces which were organised by the same stimulus categories as in Experiment 2a. The arrays were presented in colour on a black background. The stimuli were presented at a resolution of 175 x 225 pixels, sized at 5.63cm x 7.84cm. Participants sat approximately 70cm from the screen and the experiments were run on an iMac computer using Superlab 4.07b.

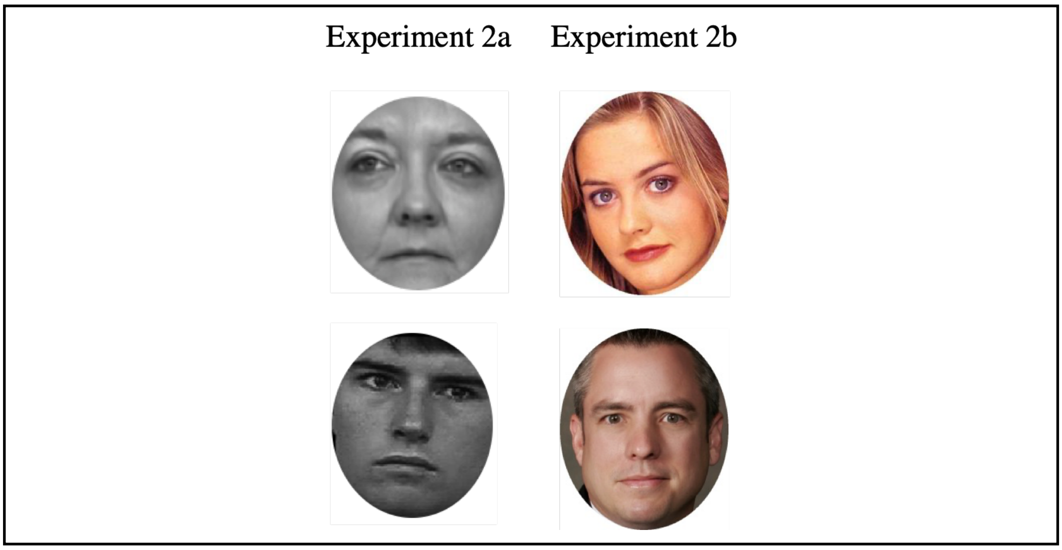

Figure 9. **shows examples of the standardised faces used in Experiments 2a and the 'realistic' faces used in Experiment 2b.**

tDCS Procedure

The neuroConn tCDS system was used deliver to the same tDCS protocol as that used in Experiment 1. In Experiment 2a and 2b, tDCS stimulation began at the beginning of the computer task and ran for the duration of the experiment (approximately 10 minutes). The tDCS was left in place until the end of the experiment to avoid unnecessary disturbance during the computer task. The tDCS procedure was double-blind using codes generated by an independent researcher which were inputted into the neuroConn box and corresponded to the two stimulation conditions.

Study Procedure

In Experiment 2a and 2b, participants completed a target detection task comprising a 'training phase' and a 'detection phase'. In the 'training phase', participants were given instructions and shown an example of a target face within an example array. Participants were then told to disregard the faces they had seen and were shown the target individual they were to search for in the 'detection phase'. Once the experiment began, a fixation cross appeared on the screen for 1000ms followed by a facial array which remained on the screen for a maximum of 4000ms. During this time, participants responded or the trial would time-out with the message 'too slow' (*figure 10)*. The response keys were counterbalanced across the participant groups so that half of the participant groups (1-8) pressed 'x' to indicate the target was present, and '.' to indicate the target was absent. The other half (groups 9-16) responded in the opposite manner. Participants were randomly assigned to the order which they completed the sub-experiments in and the experimental order was counterbalanced across tDCS conditions.

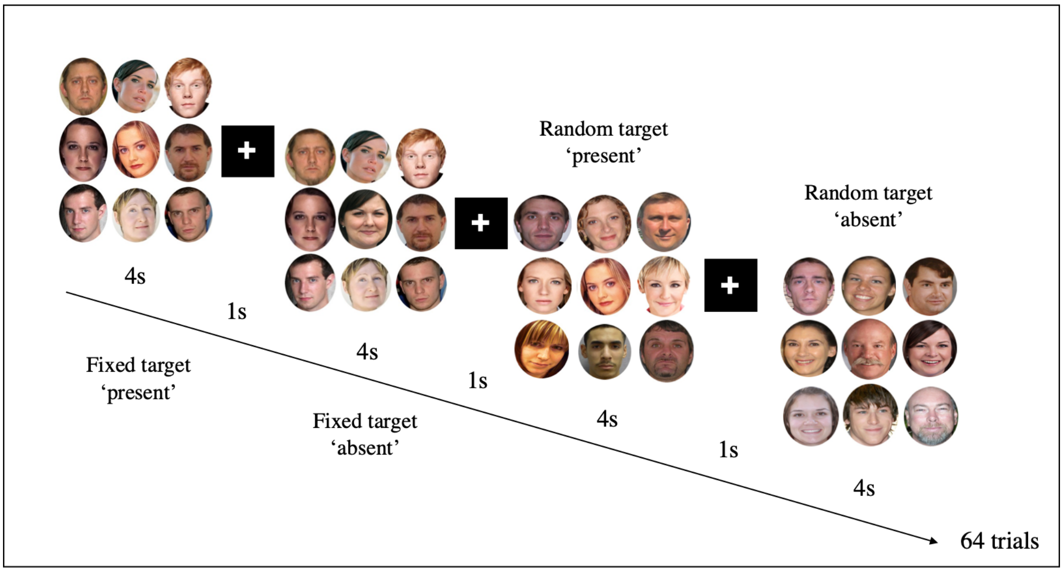

***Figure 10.* Schematic to show the trial structure in the 'detection' phase of Experiment 2a, which was identical in 2b with the 'realistic' faces replaced by the standardised ones.**

Results

Behavioural Data Analysis

As in Experiment 1, performance accuracy in the detection task was converted into a d-prime (d') sensitivity measure according to (Stanislaw & Todorov, 1999). After reviewing other target detection studies, it was decided that a measure of response bias should also be calculated. As such, criterion (C) was chosen as an appropriate measure as it is used as an indication of how judgements about the presence or absence of a signal are made. The value of C is calculated in relation to an *ideal observer*. This ideal observer would minimise the combined risk of a miss or false alarm. As such, their criterion would be located at the average of the means of the signal and noise distribution. The value of C for each participant then is the distance from the participant's threshold to the ideal observer. The equation used to calculate C was $C = (z(H) + z(F)) / 2$. This gives a value of C which is relative to the crossover point of the signal and noise distributions, which is set to 0. Therefore, C represents an internal threshold where a value exceeding C results in a signal present judgement, and a value less than C results in a signal absent judgement (Abdi, 2007). Beta (β) and the reaction times were also calculated but their analysis did not add to the interpretations of the results. As such it was decided not to include them in the main body of the text, however, a full report can be found in Appendix 2.

In order to examine whether there were any differences between the effects of tDCS on the standardised and realistic faces, a 2x2x2 ANOVA on the d' and C scores was conducted using the within-subjects factor *Background* (fixed/random) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (2a/2b). The primary analysis for the standardised faces in Study 2a and the realistic faces in 2b was a 2x2 ANOVA using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). This analysis was calculated for d 'scores and for C in each sub-experiment. Finally, paired t-tests were calculated for the C scores in Experiment 2a to examine detection performance on the different background types in each tDCS condition. F values are reported along with a measure of effect size ($\eta^2 p$) and *p*-values, which are two-tailed unless otherwise stated.

Analysis between Experiment 2a and 2b

The 2x2x2 ANOVA on the d' scores using the within-subjects factor *Background* (fixed/random) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (2a/2b) revealed a non-significant three-way interaction, $F(1,124)=.086$, $p=.769$, $\eta^2 p=.001$. However, the three-way interaction for the same 2x2x2 ANOVA on C was significant, $F(1,124)=5.108$, $p=.026$, $\eta^2 p=.04$ which suggested that the effect of tDCS differed between the standardised and realistic faces. As such, the results for Experiment 2a and 2b were analysed separately.

Experiment 2a – Standardised Faces

The 2 x 2 ANOVA for the d' scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)= .679$, $p=.413$, $\eta^2 p=.011$ and the between-subjects factor *tDCS*, $F(1,62)= .094$, $p=.76$, $\eta^2 p=.002$ were not significant. The two-way interaction was also not significant, $F(1,62)<.001$, $p=.988$, $\eta^2 p<.001$ which suggested overall that tDCS had no real effect on d' for the Standardised faces.

The same 2 x 2 ANOVA for C was calculated where the main effect of *Background,* $F(1,62)= 5.027$, $p=.402$, $\eta^2 p=.011$ and *tDCS,* $F(1,62)=.023$, $p=.88$, $\eta^2 p<.001$ were not significant however the two-way interaction was significant, $F(1,62)=5.027$, $p=.029$, $\eta^2 p=.075$. To further explicate this result, paired samples *t* tests were carried out on the C scores. The paired *t* test examining the difference between detection on the fixed and random backgrounds in the sham tDCS condition revealed criterion was significantly higher on the fixed background, $t(31)=2.381$, $p=.024$, $\eta^2 p=.155$ (Fixed background mean .238; SD .218. Random background mean .095; SD .278). The paired *t* test examining the difference between detection on the fixed and random backgrounds in the anodal tDCS condition revealed no significant difference between criterion on the fixed and random backgrounds, $t(31)=0.918$, $p=.366$, $\eta^2 p=.026$. Therefore, the significant interaction was driven by criterion being significantly higher in the fixed than random background condition in sham, which was absent in the anodal condition.

Experiment 2b – Realistic Faces

The 2 x 2 ANOVA for the d' scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)=2.773$, $p=.101$, $\eta^2 p=.043$ and the between-subjects factor *tDCS*, $F(1,62)=.088$, $p=.768$, $\eta^2 p=.001$ were not significant, but the numerical trend was in line with the hypothesis that performance would be better on the fixed backgrounds. The two-way interaction was also not significant, $F(1,62)=.242$, $p=.625$, $\eta^2 p=.004$. The same 2 x 2 ANOVA for C was calculated where the main effect of *Background,* $F(1,62)= 1.22$, $p=.274$, $\eta^2 p=.019$ and *tDCS,* $F(1,62)=.408$, $p=.525$, $\eta^2 p=.007$ were not significant and neither was the two-way interaction, $F(1,62)=.492$, $p=.485$, $\eta^2 p=.008$. It is worth noting that the pattern of results in this experiment for C was rather different in the Sham condition to that in Experiment 2a, and that this is probably the source of the significant three-way interaction.

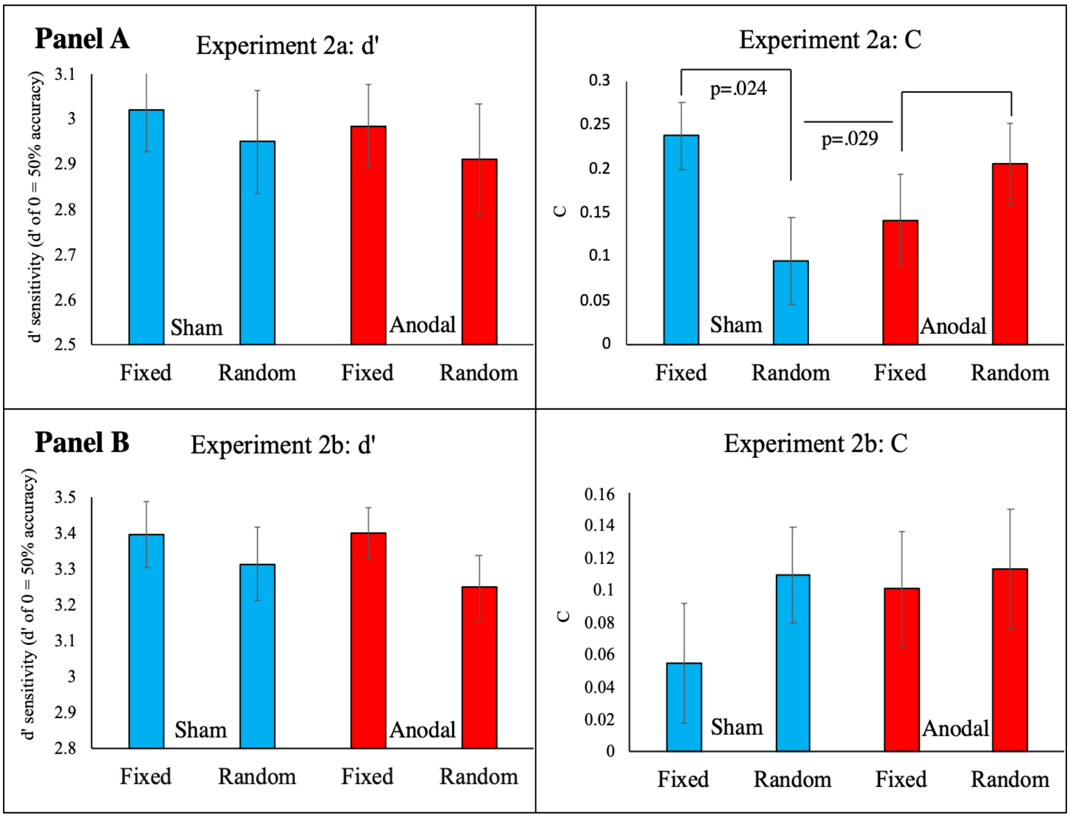

Figure 11. **Panel A shows the d' and C results from Experiment 2a. Panel B shows the d' and C results from Experiment 2b.**

Experiment 3

Experiment 3 presented chequerboards in the target detection task. A single familiar, and multiple random, chequerboards were presented to participants where a target shape, which looked like an H, either appeared in a random location or was absent. The only condition on its location was that the target shape appeared within the bounds of the chequerboard and synchronized with its squares. This ensured it did not artificially stand out due to being incorrectly lined up with the other squares. In sham, it was expected that the advantage conferred by perceptual learning would facilitate target detection on the familiar background, improving detection performance compared to the random group. In the anodal group, the predicted advantage for detection on the familiar background might be expected to be lost.

Method

Subjects

48 naïve right-handed participants were recruited from the University of Exeter. Participants completed a safety screening form, approved by the University of Exeter's Research Ethics Committee, before consenting to participate and were offered course credit or payment for their participation. Participants were randomly assigned to either to sham or anodal tDCS conditions using a double-blind procedure and to one of 8 participants groups which were used to counterbalance the stimuli and target locations.

Materials

The stimuli used were sets of 16x16 chequerboards which contained roughly half black, half white squares presented in greyscale on a black background. They were sized at 256 by 256 pixels, presented at a resolution of 1680 by 1050 pixels. The experiment was run using Superlab 5 on an iMac computer and participants were seated approximately 70cm from the screen. Two prototype chequerboards were created, from which different exemplars were made by changing 48 cells in each exemplar at random. This created two sets of exemplar chequerboards from different prototype-defined categories; A and B. The 'random' chequerboards were created by randomly allocating squares within the 16x16 cell grid to be black or white which created a third set of chequerboards totally unrelated to category A and B. The single 'familiar' chequerboard which was repeatedly shown was the prototype of one of the two categories which were familiarised in the 'categorisation' phase.

A target shape was created, *(Figure 12.)* sized at 80x80 pixels, which was designed to be symmetrical vertically and horizontally. The location of the target was determined by the co-ordinates of each of the cells in the chequerboard. In

Superlab, the co-ordinates are defined by the number of vertical and horizontal pixels counted from the centre of each chequerboard. The co-ordinates were divided into 64 'odd' and 64 'even' positions which created different positions in which the target could appear. Defining the location of the target in terms of the positions ensured that the target always lined up exactly with the cells in the chequerboard and meant the locations it could appear in could be counterbalanced across participants groups (*Figure 12).*

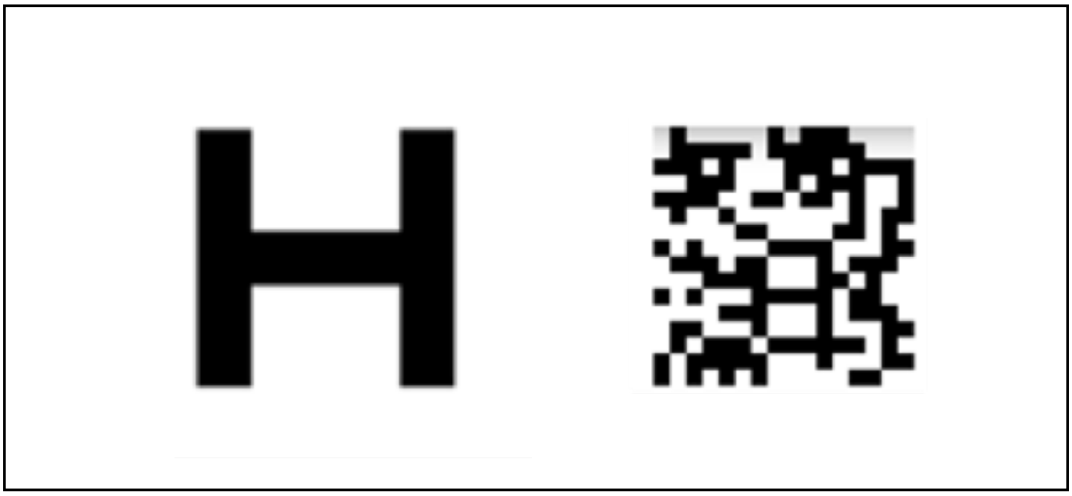

***Figure 12.* Left panel shows the target stimulus used in Experiment 3. Right panel shows an example chequerboard where the target stimulus is present in the lower**

tDCS Procedure

tDCS stimulation was run offline in this experiment, having ended during the previous computer task approximately 15-20 minutes before. The computer task completed beforehand was either Experiment 1a or 1b of this paper. Participants had been randomly assigned to tDCS groups in this previous experiment and these groups were recorded for Experiment 3.

Study Procedure

Participants completed an additional 'categorisation phase' at the beginning of the computer task in Experiment 3 before moving onto the 'training phase' and a 'detection' phases which were the same as in Experiment 2.

In the 'categorisation phase', participants sorted 128 exemplar chequerboards into two categories; category A and B created from the prototypes described above. Participants were encouraged to scan the whole chequerboard before responding, which they did using the '1' and '2' keys on the keyboard (keys were counterbalanced across participant groups). The chequerboards appeared one at a time in a random order and remained on the screen until a response had been made, or for up to 4000ms when the trial would time-out with the message 'too slow'. Participants were given immediate feedback informing them whether their response was correct.

In the 'detection phase', participants were shown the target shape and instructed that it would only appear in that size and orientation but that it could appear anywhere within the chequerboard. Participants pressed 'x' to indicate target present and '.' to indicate target absent (counterbalanced across participant groups). Over 8 blocks of 32 trials each; 256 chequerboards were presented one at a time in a random order. 128 trials with the target present (64 on the familiar background, 64 on the random background) and 128 trials with the target absent (again 64 on the familiar background, 64 on the random background). Each chequerboard was presented for 4000ms and a fixation cross was presented for 500ms between each trial. As in the 'categorisation' phase, participants were given immediate feedback as to whether their response was correct or not.

Results

Behavioural Data Analysis

As in Experiment 1 and 2, data was collected on performance accuracy which was converted into a d-prime (d') sensitivity measure according to (Stanislaw & Todorov, 1999). Criterion (C) was also calculated for each participant in the same way as in Experiment 2. Again, beta and reaction times were calculated but did not contribute to the interpretation of the results so they are not included here.

The primary analysis was a 2x2 ANOVA using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal) which was calculated for the d' and C scores. Paired *t* tests were also calculated to examine detection performance on the different background types in each tDCS condition. Finally, in the additional analysis, the C scores for the standardised faces (2a) and checkerboards (3) were analysed in a 2x2x2 ANOVA using the within-subjects factor *Background* (fixed/random) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (2a/3) to investigate whether tDCS affected the two stimulus types similarly. F values are reported along with a measure of effect size (η^2_p) and *p*-values, which are two-tailed unless otherwise stated. Analysis of the Beta (β) scores and reaction times can be found in Appendix 3.

Analysis for Experiment 3

The 2 x 2 ANOVA for the d' scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background* was significant, $F(1,46)=24.313$, $p<.001$, $\eta^2_p=.346$. The main effect of the between-subjects factor *tDCS,* $F(1,46)=.057$, $p=.812$, $\eta^2_p=.001$ was not significant. Neither was the two-way interaction, $F(1,46)=1.054$, $p=.31$, $\eta^2_p=.022$. Paired *t* tests were carried out to examine the differences between target detection on the fixed and random backgrounds between tDCS conditions. Accordingly, the paired *t* test for the d' scores in the sham tDCS ground revealed significantly better detection on the fixed than random background, $t(23)=3.979$, $p=.001$, $\eta^2_p=.408$ (Fixed background mean 3.793; SD .553. Random background mean 3.254; SD .699). The paired *t* test for the d' scores in the anodal tDCS group also revealed significantly greater detection on the fixed than random background, t(23)=2.945, *p*=.007, η^2p=.274 (Fixed background mean 3.657; SD .864. Random background mean 3.303; SD .672). This suggested tDCS had a similar effect on d' between the fixed and random trials.

The 2 x 2 ANOVA for C revealed non-significant main effects of *Background*, F(1,46)=1.065, *p*=.307, and *tDCS*, η^2p=.023 and *tDCS* F(1,46)=.132, *p*=.718, η^2p=.003 but the two-way interaction was significant, F(1,46)=5.22, *p*=.027, η^2p=.102. The paired *t* test examining the difference between detection on the fixed and random backgrounds in the sham tDCS condition revealed criterion was significantly higher on the fixed background, *t*(23)=2.542, *p*=.018, η^2p=.219 (Fixed background mean .204; SD .221. Random background mean .068; SD .165). The paired *t* test examining the difference between detection on the fixed and random backgrounds in the anodal tDCS condition revealed no significant difference between detection on the fixed and random backgrounds but the pattern reversed numerically, *t*(23)=0.826, *p*=.417, η^2p=.029 (Fixed background mean .097; SD .168. Random background mean .148; SD .214). The source of the significant interact then was that C was significantly higher on the fixed than random background in sham, but not in the anodal group.

Additional Analysis between Experiment 2 and 3

In order to examine the effect of the tDCS procedure across experiments, a 2x2x2 ANOVA using the within-subjects factor *Background* (fixed/random) and the between-subjects factors *tDCS* (sham/anodal) and *Experiment* (2a/3) was carried out on the C scores. The three-way interaction was not significant, F(1,108)=.023, *p*=.88, η^2_p<.001; showing that the effect of tDCS on the standardised faces and checkerboards did not differ significantly between the stimuli. The two-way interaction *background*tDCS* was significant, F(1,108)=9.471, *p*=.003, η^2_p=.081 showing that tDCS affected detection on the backgrounds differently, with criterion being higher on fixed than random backgrounds in Sham, and this reversing for Anodal. None of the other two-way interactions or main effects were significant.

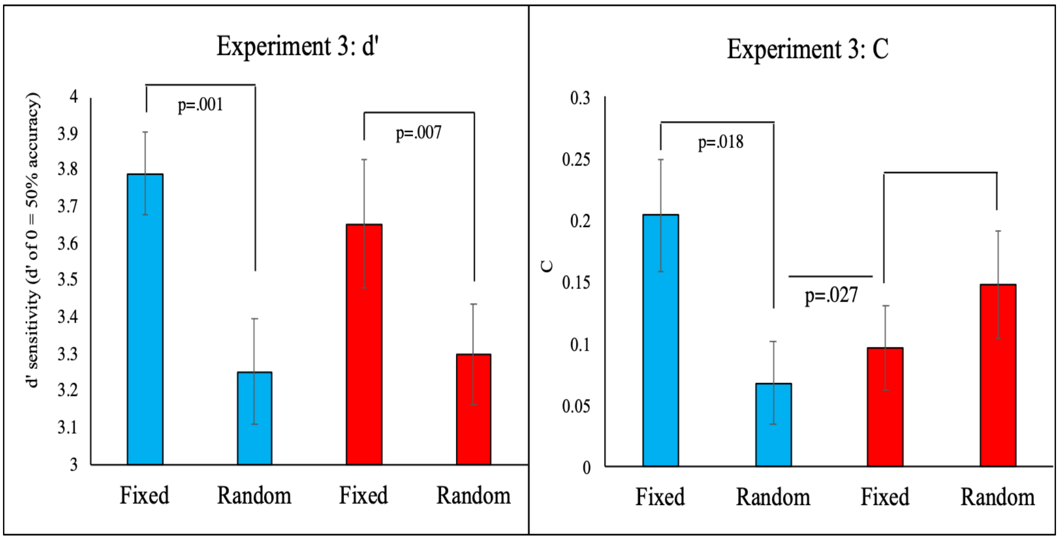

Figure 13. **Graph to show the results for *d'* and C from Experiment 3**

Discussion

The results from Experiment 2b showed that tDCS had little effect on the realistic faces in terms of *d'* or C. Furthermore, the results from Experiment 2a and 3 showed that tDCS had no meaningful effect on *d'* although the expected difference in target detection between the familiar and random backgrounds did emerge with the chequerboards. More interestingly, there seemed to be an effect of tDCS on C which emerged in Experiments 2a and 3.

In Experiments 2a and 2b detection performance on both background types was high in both the sham and anodal tDCS groups, which is visible in the large *d'* scores with no significant differences between groups. In Experiment 3, though participants were good at the task when the target appeared on both backgrounds, the target was significantly better recognised when it appeared on the fixed rather than the random background in both tDCS groups. This reflects the prediction that, according to an MKM-based analysis, the high relative salience of the target on a familiar background facilitates detection of it better than when the target appears on a random background. It also supports the explanation of target detection in terms of feature salience modulation, though tDCS did not have any significant effect on *d'* as predicted. This suggests that tDCS did not have a comparable effect on the detection task to that shown on the '*old/new recognition'* task, a result for future work to address.

However, the effect of tDCS on C was unexpected. Across Experiments 2a and 3, an interesting pattern with C emerged; significantly higher criterion for the familiar background than the random background in the sham group which was reversed numerically in the anodal group. The tDCS procedure seemed to have a very similar effect on C for both the standardised faces and chequerboards, suggesting that there is a real and robust effect here. This will be discussed further in the general discussion, along with the results from Experiment 1.

Chapter 4: General Discussion

The studies presented in this paper have tested the effect of tDCS on stimulus discrimination in two experimental tasks. Experiment 1 confirmed that the same tDCS procedure can selectively increase or reduce the face inversion effect depending on the stimuli the regular faces are presented with. Experiment 1 also showed that a set of manipulated faces, Thatcherised faces, generalise onto regular faces sufficiently to reduce the inversion effect on the latter and, when combined with previous literature, that tDCS can mitigate the effect. In the detection studies, while tDCS had no significant effect on *d'* prime, anodal stimulation did have an interesting and unexpected effect on criterion. It now remains to explain the effects in terms of a theory which can account for the perceptual learning seen with familiar stimulus categories and the disruption caused by anodal tDCS. Given space considerations, the following analysis will focus on the MKM model of stimulus representation to offer an account of the results before considering the limitations in these experiments and possible future directions.

Experiment 1

Thatcherised faces generalise onto regular faces sufficiently to reduce performance

Of significant interest in Experiment 1 was that Thatcherised faces generalise onto regular faces sufficiently to influence recognition of the regular faces themselves. The sham condition of Experiment 1b demonstrates the standard face inversion effect where upright faces are recognised better than their inverted counterparts. The MKM theory suggests that enhanced discriminability in the upright category is facilitated by latent inhibition of the common elements as experience has rendered the stimulus category sufficiently familiar (Civile et al., 2020). By replacing the female faces used in (Civile et al., 2020) with chequerboards from which no generalisation should have occurred, Experiment 1b in this sense presents a 'pure' measure of the inversion effect with regular faces. The sham condition of Experiment 1a adds Thatcherised faces into the mix which, as demonstrated with this study and (Civile et al., 2020), alters the face inversion effect seen in Experiment 1b. In that study, the authors argued that the 'super-salience' of the Thatcherised features would promote generalisation between the Thatcherised faces because they attract more learning. However, the fact that the inversion effect in Experiment 1a was smaller than in Experiment 1b shows that generalisation between the face types also occurred. As the Thatcherised and regular faces are both fundamentally faces regardless of the manipulation, it makes sense that some generalisation between shared units might occur. For example, unchanged, shared features of the face such as the nose should promote generalisation between stimulus categories and the more salient of these unchanged features would make 'old/new' discriminations for the regular faces harder. Yet of greater interest is the fact that highly salient Thatcherised features seem to have increased the salience of those unchanged features by altering their prediction error with the effect of making 'old/new 'discriminations on 'new' regular faces harder. Therefore, in the sham groups, it seems that unhelpful generalisation from the Thatcherised faces to the regular faces occurred and was sufficient to reduce the inversion effect in regular faces compared to a situation where no generalisation from the chequerboards onto the regular faces is likely to have occurred. As far as I am aware this is a novel finding in the literature.

tDCS frees regular faces from the unhelpful generalisation which occurs from Thatcherised faces

At the same time, the collated results revealed that anodal tDCS increases the inversion effect for regular faces presented with Thatcherised faces, though Experiment 1a itself failed to replicate this result. Given the increased sample size from the 2020 paper, it is unclear why this occurred and this is quite a significant limitation of this set of results.

The anodal condition of Experiment 1b replicated the now established finding that anodal stimulation reduces the face inversion effect compared to sham Civile et al. (2018, Civile, Obhi & McLaren, 2019, Civile et al., 2020). The theoretical analysis offered suggests that anodal stimulation disrupts perceptual learning by disabling the modulatory input based on prediction error. The MKM theory of perceptual learning predicts that associations producing low error terms in the common features reduces their salience relative to the unique elements. With anodal stimulation, however, those same associations instead boost the salience of the common features relative to the unique ones. As the common elements become the most salient, 'old/new' discrimination is made harder because the stimuli appear more similar and thus performance drops relative to sham. The MKM theory would suggest that the drop in performance for the upright faces occurs disproportionately to that in the inverted faces because, as an unfamiliar category of stimuli, the elements of the inverted stimuli are equally unpredicted so the standard perceptual learning effect which appears with upright faces does not apply. Thus, the reduced performance for upright faces in the anodal condition resulted in a significantly reduced face inversion effect compared to sham in Experiment 1b.

In the combined results for Experiment 1a and previous work, however, the inversion effect in the anodal group was significantly increased compared to sham. Applying the same analysis to this situation, using tDCS to disrupt feature salience modulation can be considered to reduce the unhelpful generalisation which previously occurred between stimulus categories in sham. By removing this unhelpful generalisation, the regular faces are freed and the inversion effect subsequently increases. This is in direct contrast to the reduced inversion effect seen in the anodal condition of Experiment 1b, where again no generalisation between stimuli categories was thought to have taken place. Overall then, the results support the conclusion reached by Civile et al. (2020) by showing that tDCS can selectively increase or reduce the inversion effect for regular faces by changing the stimuli those regular faces are presented with. And indeed, characterising the effect of tDCS as disrupting feature salience modulation has the benefit of being able to account for the opposite results found in Experiment 1a and 1b. In 1b, it explains how tDCS increases generalisation between upright regular faces when presented with other regular faces. Yet in 1a, it explains how tDCS disrupts unhelpful generalisation between Thatcherised and regular faces. Finally, Experiment 1 provides further evidence that tDCS does not simply make people 'worse' at processing upright faces. In the correct circumstance, it can in fact make people better.

The 'other' stimuli

Civile et al. (2020) found anodal stimulation to significantly increase the inversion effect for Thatcherised faces compared to sham. Yet in this Experiment, neither the results from Experiment 1a or the collated analysis revealed a significant effect of tDCS on recognition of Thatcherised faces. It appears then that if tDCS does have an effect on Thatcherised faces themselves, it is not a large one. This was not wholly unexpected as performance on the Thatcherised faces has tended to be lower than that for regular faces in previous studies (see Civile et al., 2020). However, future studies could attempt to replicate the results with a larger sample to see whether any effect of tDCS on the Thatcherised faces themselves emerges.

The other unexpected result came from the chequerboards in Experiment 1b where there was no inversion effect in the sham group and no significant effect of tDCS on the inversion effect. This is despite previous studies having shown a significant inversion effect for familiar chequerboards in the 'old/new recognition task' and that anodal stimulation significantly reduces that inversion effect compared to sham (Civile et al. 2016). It is possible the timing of the tDCS stimulation affected the results due to the additional training phase in Experiment 1b. The additional training phase meant that the stimulation occurred a longer time before the test phase than in Experiment 1a. Not enough is currently known about how long the effects of this type of neuro-stimulation outlast the tDCS stimulation itself to confidently say that the design did not affect the results. For example, Ambrus et al. (2011) describe how the effect of stimulation at 1mA intensity over M1 can outlast the stimulation itself for over an hour, whereas the after-effects of simulation at the same intensity over visual cortex typically lasts 10-20 minutes. The training phase was deemed necessary in this particular design because the chequerboard stimuli were unfamiliar. The decision to use unfamiliar chequerboards was taken in order to control participants previous experience with the stimuli which was deemed important to make them a viable comparison stimulus to the unfamiliar faces. Therefore, future studies could consider using an additional catgeorisation phase using distractor stimuli in Experiment 1a which would standardise the tDCS timings between sub-experiments. This would be preferable to using an already familiar set of stimuli instead of the chequerboards for which participant's experience could not be so easily controlled.

It is also possible that in this experiment, participants did not fully attend to the chequerboard stimuli, treating them instead as masks or distractors which could account for the very low performance. However, towards the end of the study, a failure in the counterbalancing with the chequerboards was also unfortunately discovered. For some participants, the keys pressed to categorise exemplars from category A and C (during the categorisation phase) were not properly counterbalanced with those pressed in the recognition task. The error was fixed for the last 24 participants, however, the failure does make the lack of any effect with the chequerboards difficult to interpret. Despite this, it should be noted that the counterbalancing error does not have any implications on the results with the regular faces. Furthermore, the chequerboards and Thatcherised faces were not of primary interest in this study as they were mainly used to influence performance on the regular faces. Therefore, the limitations with the 'other' stimuli are not likely to compromise the results with the regular faces.

tDCS and the face processing literature

The results contribute to a line of research investigating the effect of tDCS on face perception and, though there have been many studies conducted, few have tested the effect of tDCS on face recognition directly. Barbieri, Negrini, Nitsche and Rivolta (2016) investigated whether tDCS could causally enhance face processing by applying online (tDCS during task execution) and offline (tDCS prior to task execution) anodal tDCS (1.5mA intensity) to right occipital cortex at point P08. The results showed that offline tDCS improved perception and memory performance of faces and objects but online tDCS did not. In another study, Brunyé, Moran, Holmes, Mahoney and Taylor (2017) investigated whether anodal stimulation of the right fusiform gyrus (within which the FFA is located) could selectively increase working memory for faces versus non-face objects (houses).

Participants took part in two test sessions separated by at least 24 hours. In one, anodal stimulation was delivered to point PO10 at 0.5mA and in the other 1.5mA for the duration of the working memory task. Participants completed the Cambridge Face Memory Task (CFMT) to assess individual face recognition ability before moving onto a working memory task which manipulated working memory load by varying the set sizes from 1-4 items; either faces or houses. The results showed that 1.5mA anodal stimulation increased the number of items stored in working memory for faces, but not for houses. The authors concluded their results support functional specialisation of right fusiform gyrus to maintain faces, but not non-face objects, in working memory. Though the stimulation procedure and theoretical analysis used in Experiment 1 differs from these studies, taken together, the evidence points to the ability of tDCS to modulate, and in some cases enhance, face recognition skills.

Perhaps the most popular theory of Perceptual Learning which should also be discussed in relation to these results is the 'comparison' theory which suggests that perceivers are able to tell similar stimuli apart after exposure to them because they are able to explicitly compare the stimuli and, therefore, notice differences between them. However, it is difficult to see how this theory could convincingly accommodate these results given that both the faces and chequerboards were novel. Indeed, the facial stimuli were specifically chosen to be from an anonymized database and did not include any celebrities which might be familiar to participants. The same is also true of the chequerboard stimuli. While it is certainly true that participants have a level of experience with the former stimulus group, having been exposed to them over their lifetime, it is still difficult to see how a comparison theory could accommodate the results with novel stimuli taken from this category, particularly the chequerboards, on the earlier trials. However, it is perhaps plausible that participants could be going through a comparison process on the later trials and this is a possibility that future experiments could explore. This also goes to a broader point discussed by Mundy, Honey and Dwyer (2007) that multiple mechanisms are likely to contribute to perceptual learning at different times and places. So, while an associative account seems to explain this set of results most convincing, that is not to say that a comparison-based process could not have played a part in the experiments described here.

A final statistical caveat needs to be made which also applies to the results from Experiment 2 and 3 that will be considered next. Due to space and time considerations, I have relied on cross-experiment analyses in this thesis and drawn conclusions about the absence of material effects on the basis of null results using null hypothesis significance testing (NHST). This presents some problems which future studies could address with the addition of Bayesian and/or equivalence testing which would certainly provide a fuller picture of the results. For example, one of the common criticisms of NHST procedures are their sensitivity to sample size which can lead to important effects being presented as non-significant in studies with small samples and conversely, impressive *p* values appearing to represent in fact trivial effects in studies with large samples sizes (Levine, Weber, Hullet, Park & Lindsey, 2008). Thus, I acknowledge that drawing firm conclusions on the basis of NHST procedures alone is not ideal and could certainly be improved upon in the future, most especially with Experiments 2 and 3 which lacked the prior experiments to guide and inform the theory that Experiment 1 benefitted from. Nevertheless, given the substantial sample sizes used in these experiments, they do provide a basis for any future work and analysis. Ultimately, replication will be needed to confirm the effects (or lack of them) reported here.

Experiment 2 and 3

Experiment 1 established the effects of tDCS on the *'old/new recognition'* paradigm. Experiment 2 and 3 went on to explore how anodal stimulation could affect performance in a different situation where disrupting feature salience modulation, to increase generalisation between a stimulus category or disrupt unhelpful generalisation, could confer an advantage. The target detection experiment represented this more 'real world' situation.

tDCS and d'

On the 'realistic' faces, the results showed no real effect of tDCS on *d'* or C. The relative lack of experimental control over the 'realistic' faces, compared to the standardised ones, could explain why there seemed to be no effect on them. It might also be due to a ceiling effect, as performance was very high for these faces, higher than for the standardized ones (note that the high d' for the chequerboards in Experiment 3 is partly due to the larger number of trials given in that experiment). What was striking about the results from Experiment 2a and 3, however, was just how similar they were. In both experiments, target detection was superior on the familiar compared to the random background, though only significantly so in Experiment 3. Additionally, while there was no significant effect of tDCS on *d',* there was a significant effect of anodal stimulation on C in Experiment 2a and 3. As a similar pattern appeared numerically in Experiment 2a and 3, the analysis that follows applies to both and suggests a shared causal mechanism might be active in both experiments.

On the basis of previous studies investigating mechanisms of change detection, target detection was expected to be easier on the familiar than the random chequerboards. An analysis using the MKM model would predict that the salience of the target to be high on the familiar background compared to the background features because error-based salience modulation leads to a decline in salience of the well-predicted features of a stimulus. Thus, when the target is present, it is unexpected, unpredicted and has higher relative salience than the background elements which causes it to 'pop-out'. The random background, however, has not been familiarised over multiple presentations. As a result, perceptual expertise with each stimulus has not built up and the background features will be equally unpredicted. Thus, when the target appears, it too will be equally unpredicted so the crucial salience difference between the target and the background will be absent. Target detection on this random background should be much harder and a serial search is likely to be needed to detect the presence or absence of the target. This account was in fact borne out in both experiments as detection was superior on the familiar background in both tDCS conditions; and is a novel finding with this particular target detection paradigm.

By extrapolating the interpretation of tDCS' mechanism of action in Experiment 1, it was thought perhaps that tDCS might reduce the advantage for target detection on the familiar background by disrupting feature salience modulation. It was tentatively suggested that in doing so, tDCS may increase generalisation between the common element of a stimulus category, or reduce generalisation between similar stimuli. Looking at the performance on both the familiar and random backgrounds, though participants were better in the familiar condition, they scored highly on both. Therefore, it seems possible that the task was again too easy to detect any real effect of tDCS. Berryhill, Peterson, Jones and Stephens (2014) argue that tDCS is unlikely to alter supraliminal (above the threshold of consciousness) responses precisely because it modulates the state a network is in at the time of task execution. So, when a participant categorically knows an answer or is fairly sure (say 80-99% certainty), tDCS is unlikely to have an effect. Instead, the effect of tDCS appears on near-threshold judgments; for example it could change a 48% certainty to say 53% which would change the final decision. In future experiments, it seems pertinent then to increase the task difficulty to bring performance down closer to threshold where an effect of tDCS might make itself visible. For example, the ‘clumpy’ chequerboards in Experiment 3 could be replaced with harder, ‘non-clumpy’ chequerboards as used in Civile et al. (2014).

However, it is also true that the detection task with faces and chequerboards did not exactly match. In the face detection task, participants searched for a face within a 9-piece array whereas in the chequerboard task participants searched for a target shape within a single chequerboard. Therefore, more directly comparable tasks could be constructed in the future whereby a single face was searched for, for example, within an image of a crowd. The crowd could be structured as with the chequerboards, or individuals could appear randomly within the bounds of the image which would be more naturalistic. Doing so might go some way to increasing the task difficulty in the face detection task as well as making it possible to draw more direct comparison between the face and chequerboard detection task. It may also make it easier to detect an effect of tDCS on *d’* if indeed there was one and would present a more ‘realistic’ situation closer to what security analysts face in the workplace.

Finally, the timing of tDCS stimulation in Experiments 2 and 3 differed from Experiment 1. While in Experiment 1, stimulation finished before the start of the ‘recognition’ phase, in Experiment 2 it ran for the duration of the task and Experiment 3 was conducted offline, such that stimulation finished 15-20 minutes prior to the start of the task. Given the differences in stimulation timing between the experiments, it is possible that tDCS stimulation impacted the encoding and retrieval of information in Experiment 1, 2 and 3 differently. Future experiments could address this problem by waiting until the full 10 minute stimulation period had finished before beginning the detection tasks, for example giving participants an unrelated computer-based task to perform during this time.

That there was no significant effect of tDCS on *d'* differs from other similar detection studies. For example, Olma et al. (2011) found that 1mA anodal stimulation to left occipital cortex for 15 minutes significantly improved performance, calculated by detection sensitivity, in a visual contrast discrimination task compared to cathodal and sham stimulation. Though there was no effect of anodal or cathodal stimulation on response bias (criterion). Similarly, Falcone, Coffman, Clark and Parasuraman (2012) showed that anodal stimulation significantly improved perceptual sensitivity (increased *d'*) and accelerated learning of a complex threat detection task using humans and objects, which was also maintained for 24 hours afterwards. The tDCS procedure applied anodal stimulation over right inferior frontal cortex at point F10 at 2mA intensity for 30 minutes. The performance enhancement was in fact so extensive that perceptual sensitivity in the active group was more than double that in the control group at the end of the task. The authors argued the increased sensitivity could not reasonably be explained by a general increase in arousal because there was no corresponding increase in response bias. Instead, the authors suggest tDCS improved the ability to encode the features of the stimulus which facilitated target detection. This account, the authors suggest, is consistent with the view that tDCS enhances attention which functions in this kind of detection task by reducing distraction from proximal features and enhancing detection of the target feature as a result. Overall then, that there was no significant effect of anodal stimulation on *d'* is somewhat at odds with other similar studies in the literature.

tDCS and C

Despite the lack of any significant effect on *d',* something interesting did emerge with C in the 'standardized' faces and chequerboards experiments. In sham, criterion was higher for the familiar than random condition which was a novel finding in this task. However, additionally in the anodal group the pattern was reversed, and this pattern was significantly different to that in sham. The decision to explore the effect of tDCS on criterion as well as *d'* was taken because this was a novel paradigm being explored for the first time. The same analysis was retrospectively conducted on the results from Experiment 1, however, there was no significant effects of tDCS on criterion found in that experiment.

It is possible that participants actively changed their criterion between the fixed and random trials, and that tDCS disrupted the ability to do so. However, as the design was within-subjects and participants did not know which background they would see on each trial before it appeared, it seems unlikely that they actually could adopt such a strategy. Furthermore, the debrief after Experiment 3 revealed that many participants did not notice that 50% of the chequerboards were repeated. Therefore, it does seem unlikely that participants were dynamically changing their decision criterion between the fixed and random trials.

Thus, it remains unclear why and indeed how tDCS had a significant effect on criterion in these detection tasks. In contrast to the results from Experiment 2 and 3, Falcone, Coffman, Clark and Parasuraman (2012) found that anodal stimulation significantly affected sensitivity while leaving response bias unaffected. And in contrast again, Nelson et al. (2014) found anodal stimulation to significantly affect both sensitivity and bias which the authors argue supports a 'vigilance decrement' account of tasks requiring sustained attention. In this study, anodal stimulation to l-DLPFC at 1.0 mA intensity for 10 minutes beginning at either 10 or 30 minutes after the start of the behavioural task was shown to significantly increase target detection performance compared to cathodal stimulation and sham. Overall, the authors suggest tDCS helped with the task requiring sustained attention by reducing vigilance decrement which appears over time with fatigue. The authors also suggest that the increased sensitivity in the anodal group could have resulted from an enhancement of local feature processing in a strikingly similar way to Falcone, Coffman, Clark and Parasuraman (2012). No full account of why tDCS also altered response bias was offered. It is clear then that an explanation for why response bias might be altered by anodal stimulation is a question for future research, whether it occurs with or without a corresponding increase in sensitivity. Nelson et al's. (2014) experiment is also of particular interest because of its application to real-life tasks. Feltman et al. (2020) argue a major barrier to the use of neurostimulation in a military context currently is a lack of evidence showing transferability from lab-tasks to operational ones which require multiple cognitive processes. Future studies could begin by designing tasks to directly simulate those which would eventually be the target of neurostimulation in the field.

Conclusion

Over three experiments, the results have shown that tDCS to Fp3 can modulate old/new recognition and target detection for faces and chequerboards. In the '*old/new recognition'* task, tDCS was shown to selectively increase or reduce the inversion effect for regular faces simply by changing the stimuli those regular faces were presented with. This result provides further evidence that tDCS actively changes the way faces are processed. Also of considerable interest is the fact that a set of manipulated faces generalise onto regular faces sufficiently to reduce performance on the latter; an effect which tDCS can reliably ameliorate and the first demonstration in the literature of such an effect to my knowledge. The detection tasks showed that tDCS can alter criterion for standardised faces and chequerboards while leaving *d'* comparatively unaffected. Overall, the general similarity of the standardised faces and chequerboard results suggests that a general mechanism could underly both results; in a strikingly similar way to the '*old/new recognition'* task used in Experiment 1. Once again, these experiments demonstrate the utility of the MKM theory to explain and account for a sophisticated set of behavioural results, whilst leaving quite a few questions here to be answered in the future.

Appendix 1 : Experiment 1 Additional Statistics

Experiment 1a		**Experiment 1b**	
Sham Upright x Inverted Thatcherised	$t(31)=.987$, $p=.331$, $\eta^2 p=.03$ (Upright faces mean .629; SD .481, Inverted faces mean = .502; SD .675)	Sham Upright x Inverted Chequerboard	$t(31)=.456$, $p=.652$, $\eta^2 p=.007$ (Upright chequerboard mean .044; SD .516, Inverted chequerboard mean = .098; SD .437)
Anodal Upright x Inverted Thatcherised	$t(31)=2.375$, $p=.024$, $\eta^2 p=.154$ (Upright faces mean .634; SD .611, Inverted faces mean = .339; SD .519)	Anodal Upright x Inverted Chequerboard	$t(31)=1.05$, $p=.302$, $\eta^2 p=.034$ (Upright chequerboard mean .276; SD .472, Inverted chequerboard mean = .158; SD .526)

Appendix 2 : Experiment 2 Additional Statistics

Experiment 2a

The 2 x 2 ANOVA for the β scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)= 1.263$, $p=.265$, $\eta^2_p=.02$ and the between-subjects factor *tDCS*, $F(1,62)= .042$, $p=.839$, $\eta^2_p=.001$ were not significant. The two-way interaction was also not significant, $F(1,62)= 2.707$, $p=.105$, $\eta^2_p=.042$ which suggested overall that tDCS had no real effect on β for the Standardised faces.

The 2 x 2 ANOVA for the reaction times was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)= .014$, $p=.906$, $\eta^2_p<.001$ and the between-subjects factor *tDCS*, $F(1,62)= .521$, $p=.839$, $\eta^2_p=.007$ were not significant. The two-way interaction was also not significant, $F(1,62)= 2.037$, $p=.158$, $\eta^2_p=.032$ which suggested overall that tDCS had no real effect on reaction times for the Standardised faces.

Experiment 2b

The 2 x 2 ANOVA for the β scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)= .475$, $p=.493$, $\eta^2_p=.008$ and the between-subjects factor *tDCS*, $F(1,62)=.329$, $p=.568$, $\eta^2_p=.005$ were not significant. The two-way interaction was also not significant, $F(1,62)=.306$, $p=.582$, $\eta^2_p=.005$ which suggested overall that tDCS had no real effect on β for the realistic faces.

The 2 x 2 ANOVA for the reaction times was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,62)=18.018$, $p<.001$, $\eta^2_p=.225$ was significant but the between-subjects factor *tDCS*, $F(1,62)=.001$, $p=.98$, $\eta^2_p<.001$ was not significant. The two-way interaction was also not significant, $F(1,62)=1.301$, $p=.258$, $\eta^2_p=.021$ which suggested overall that tDCS had no real effect on reaction times for the realistic faces.

Appendix 3 : Experiment 3 Additional Statistics

The 2 x 2 ANOVA for the β scores was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,46)=2.238$, $p=.141$, $\eta^2_p=.046$ and the between-subjects factor *tDCS*, $F(1,46)=.295$, $p=.589$, $\eta^2_p=.006$ were not significant. The two-way interaction was not significant, $F(1,46)=6.147$, $p=.071$, $\eta^2_p=.118$ which suggested overall that tDCS had no real effect on β for the chequerboards.

The 2 x 2 ANOVA for the reaction times was calculated using the within-subjects factor *Background* (fixed/random) and the between-subjects factor *tDCS* (sham/anodal). The main effect of the within-subjects factor *Background,* $F(1,46)=.179$, $p=.675$, $\eta^2_p=.004$ and the between-subjects factor *tDCS*, $F(1,46)=.759$, $p=.388$, $\eta^2_p=.016$ were not significant. The two-way interaction was also not significant, $F(1,46)=.227$, $p=.636$, $\eta^2_p=.005$ which suggested overall that tDCS had no real effect on reaction times for the chequerboards.

Appendix 4 : Informed consent form

Informed Consent form approved by the University of Exeter's Research Ethics Committee.

UNIVERSITY OF EXETER
INFORMED CONSENT STATEMENT/INFORMATION LETTER
Department of Psychology

You are invited to participate in a research study. The present research will aim to study the neurocognitive basis of perceptual learning. The specific experiment is part of a final year student project being conducted under the supervision of Dr Ciro Civile, Lecturer in Psychology (c.civile@exeter.ac.uk).

PURPOSE OF THE STUDY
Perceptual learning is fundamental to human cognition. It can be defined as an enhancement in the ability to distinguish between similar stimuli (that otherwise would be very hard to tell apart) as a consequence of experience with them, or with stimuli similar to the target stimuli. The following experiment examines the mechanisms responsible for perceptual learning and how this phenomenon may be (at least in part) responsible for individuals' ability to recognise faces.

BEHAVIOURAL AND NEUROPHYSIOLOGICAL PROCEDURES
The experiment will take place in the Psychology Department laboratories at the University of Exeter. In total, approximately 100 participants from the university will be recruited. Participants will be over 18 years old, right-handed, not currently taking any psychoactive medications, and have no known physical, psychological, or neurological impairments. More specification about recruitment criteria will be provided linked to every neuroscience technique that will be used in different versions of the experiment.
The behavioural paradigm will consist of an old/new recognition task often used in the face recognition literature. Participants will be asked to first categorise and then memorise a set of faces presented on a computer screen for 2-4 secs. Following this they will be asked to respond (by pressing different keys) to further sets of stimuli to indicate whether or not they think they have seen them before. The behavioural task alone should take approximately 20 mins and a total of 300 face stimuli will be presented. During the task, participants will be given short breaks to rest their eyes. Some details of this study cannot be revealed to the participants at this time, but will be explained in a debrief at the end of the study.
During this study, we will be using **transcranial direct current stimulation (tDCS)**. TDCS is a safe, non-invasive and painless technique that involves delivering a weak electric current (typically < 2mA) through electrodes on the scalp. The current induces small changes in cortical excitability, which alters neural functioning. tDCS was reintroduced as a neuro-modulation technique around the turn of this century. It is currently used in a large number of universities and hospitals worldwide to study and improve brain functioning in normal volunteers and patients. The technique is considered to be generally safe for use in neurologically healthy individuals. Either during the stimulation, or in addition to stimulation, participants will perform the behavioural task described above. The tDCS stimulation will be delivered for 10-15

mins with an intensity of <2mA at brain areas found in the literature to be responsible for learning and/or face/object recognition.

RISKS

-The **behavioural study** does not involve any risk.

-Are there any risks associated with tDCS?

- tDCS is generally considered to be safe. Unlike some other brain stimulation techniques, tDCS neither causes epileptic seizures nor reduces the seizure threshold. Thus, seizures do not appear to be a risk for healthy subjects. However, this may not be true for patients with epilepsy. **Therefore, it is important that you tell us now if you have ever experienced a seizure yourself, or if there is any history of seizures in your family.** To help us determine whether you are eligible to have tDCS, you will be asked to complete a safety questionnaire which contains a number of questions about previous medical conditions involving the brain, whether you have any implants that contain metal, and any current medications. If you have any of the known risk factors, you may not be eligible to participate in this research.

- **Other potential adverse effects of tDCS**

- The most common transient adverse effects are mild tingling sensations, light itching sensations, or more rarely, a light burning sensation. These effects typically occur at the beginning of the tDCS, and disappear quickly. Participants sometimes reported transient headaches, mild discomfort, or skin irritation. These are generally mild discomforts that respond promptly to aspirin, panadol or other common analgesics. Note that mild redness under the electrodes is usually not a hint of skin damage, but most probably caused by neurally driven dilation of blood vessels, which is not harmful.

- In rare cases (2-3%), tDCS might lead to nausea or dizziness. **If you feel any pain, nausea, or other discomfort during the procedure please alert the experimenter immediately so that testing can be discontinued.**

- Certain factors can influence how you will respond to tDCS. These include fatigue, or recent consumption of alcohol or drugs. Therefore, prior to each session involving tDCS, we will ask if you have consumed more than three units of alcohol or any recreational drugs 24 hours before the session, if you have had a good night's sleep, and if you have consumed more than two cups of coffee in the two hours before the session. If your answer predisposes you to an increased risk of adverse effects, then we will arrange an alternative time for your testing session.

- Finally, it is important to realise that tDCS has only been studied systematically for the last 10-15 years and there is still more to be learned about it. Neither animal nor human studies have shown any risks of long-term effects to the brain or its functions after tDCS, but there are few relevant data in humans to date. Therefore, adverse effects that cannot be foreseen today are theoretically possible.

- **Are there any restrictions for those wishing to take part?**

- You must be over 18, generally healthy and right-handed. Because tDCS involves applying a weak current to the brain, some people are excluded. You must be able to say 'NO' to the first 22 questions in the Safety Screening Questionnaire, which is attached to this information sheet. Otherwise, please do not volunteer.

- **What do I have to do before the tDCS sessions?**

- Certain factors can predispose an individual to an adverse effect during tDCS. These include fatigue, recent consumption of alcohol or recreational drugs, or a

large amount of caffeine.
Prior to each session, please ensure that:

- **In the last 12 hours, you have not consumed more than 3 units of alcohol**
- **Not taken recreational drugs in the last 24 hours**
- **Had a good night's sleep and feel alert**
- **In the last 2 hours, not consumed more than 2 cups of coffee**

BENEFITS

Participation in this study will help us to advance the current understanding of the psychological mechanisms that enable humans to recognize faces. The experimenter will elaborate on the benefits from the present study after it has been completed during the debrief.

DATA PROTECTION AND CONFIDENTIALITY

All data about participants is strictly confidential and will not be shared with anyone outside the research team. All the electronic data (reaction time, accuracy, error, electrophysiological) will be marked with a generic participant code and only the research team will be able to link this code back to a participant's name. This link will be kept separate from the participant data and destroyed at the end of the project. These data will be stored on password protected lab computers and on Dropbox. The Dropbox folder containing the electronic data will be shared only among the research team. Also, the anonymised data associated with the publications will be deposited into the University of Exeter open access repository, ORE (Open Research Exeter). Collection of hard copy personal data for tDCS/TMS/fMRI screening purposes and consent forms, will be protected under current Data Protection legislation (General Data Protection Regulation) and University of Exeter Information Governance policies. Therefore, these will be stored securely and not copied, and will not be transformed into electronic format or uploaded onto a server. Thus, these data will be stored in locked cabinets in a locked office (Washington Singer Building). Access to these hard copy records is limited to the research team. All appropriate measures will be taken to ensure confidentiality. The hard copy records will be kept for 10 years after which they will be destroyed by Dr Ciro Civile. Any publications arising out of this research will not mention any personal details about participants. In any publications in which individual data is presented participants will be referred to by a number. There will be absolutely no way in which readers of published studies can link individual performance data back to a particular participant.
Due to recent regulatory changes in the way that data are processed (General Data Protection Regulations 2018 and the Data Protection Act 2018), the University of Exeter's lawful basis to process personal data for the purposes of carrying out research is termed as a 'task in the public interest'. The University will endeavour to be transparent about its processing of your personal data and this information sheet should provide a clear explanation of this. If you do not have any queries about the University's processing of your personal data that cannot be resolved by the research team, further information may be obtained from the University's Data Protection Officer by emailing dataprotection@exeter.ac.uk or at www.exeter.ac.uk/dataprotection. If you have any concerns about how the data are controlled and managed for this study then you can also contact the Sponsor Representative, Pam Baxter, Senior Research Governance Officer: p.r.baxter2@exeter.ac.uk

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed; however, your data cannot be withdrawn after data collection is complete because they are stored without identifiers. You have the right to omit any question(s)/procedure(s) you choose.

WHO HAS REVIEWED THE STUDY?

The study has been reviewed and approved by the University of Exeter School of Psychology Ethics Committee. If you have questions about your rights as a participant in this research, or if you feel that you have been placed at risk, you may contact the Chair of the Ethics Committee, Dr. Nick Moberly (email: N.J.Moberly@exeter.ac.uk) School of Psychology, University of Exeter, Perry Road, Exeter EX4 4QG.

MORE INFORMATION

If you require more information and feedback about the study and its results please contact Dr. Ciro Civile (c.civile@exeter.ac.uk).

FEEDBACK AND PUBLICATION

The results from the study will provide us with data that we intend to present within the School of Psychology, University of Exeter and an article will be submitted for publication. You will not be identified in any presentation of the data. A copy of the study findings can be provided by Dr Ciro Civile, on request.

Appendix 5 : Participant consent form

INFORMED CONSENT

I have read the above INFORMED CONSENT STATEMENT/INFORMATION LETTER and I understand that: **(i)** My personal identifiable data (consent form and safety screening questionnaire) will be stored in a locked filing cabinet in a locked university office. All the electronic data (reaction time, accuracy, error, electrophysiological) will be marked with a generic participant code and only the research team will be able to link this code back to a participant's name. My electronic data will be stored on password-protected university computers and will be associated with a code that only researchers are able to link with personal details; **(ii)** Access to hard copy records is limited to the research team; **(iii)** All appropriate measures will be taken to ensure confidentiality; **(iv)** The hard copy records will be kept for 10 years after which they will be destroyed by Dr Ciro Civile; **(v)** Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed.

I agree to participate in this study.

Please also provide your e-mail address, indicating whether you would like to receive feedback about the study's results.

Age ______________________________

Gender ______________________________

Ethnicity ______________________________

Participant's name ________________________________

Participant's signature______________________________
Date______________________

Participant's e-mail________________________________ Feedback? Y___ N___

Investigator's signature____________________________
Date____________________

Appendix 6 : tDCS screening form

Transcranial Stimulation safety-screening questionnaire!

UNIVERSITY OF EXETER

NAME OF PARTICIPANT ……………………………………………………………………………

Left or right handed?……………………………………………… Sex: M / F

Date of birth……………………………………………………………………………

Have you previously had an MRI scan at the University of Exeter? Yes/No

If so, are you happy for us to access your existing MRI data in this study? Yes/No

Before receiving Transcranial Stimulation, please read the questions below carefully and provide answers. For a small number of individuals, brain stimulation may carry an increased risk of causing a seizure. The purpose of these questions is to make sure that you are not such a person. You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive. The information you provide will be treated as strictly confidential and will be held in secure conditions. If you are unsure of the answer to any of the questions, please ask the person who gave you this form or the person who will be performing the study.

	Yes	No
Do you suffer from epilepsy, or did you ever have a seizure or convulsion?		
Does anyone of you close relatives have epilepsy?		
Have you ever had severe (i.e., followed by loss of consciousness) head trauma?		
Have you ever had a severe concussion?		
Did you ever suffer from a condition to your brain, such as meningitis?		
Did you ever have a stroke?		
Do you suffer from multiple sclerosis?		
Do you have brain damage, as a result of brain surgery or a disease?		
Did you ever have a surgical procedures to your spinal cord?		
Do you have spinal or ventricular derivations?		
Do you suffer from another neurological condition?		
Do you have metal in the brain/skull (except titanium)? (e.g., retainer, splinters, fragments, surgical clips, etc.)		
Do you have cochlear implants?		
Do you have an implanted neurostimulator? (e.g., DBS, epidural/subdural, VNS)		
Do you have a cardiac pacemaker or intracardiac lines or metal in your body?		
Do you have a medication infusion device?		
Do you have a history of drug abuse or alcoholism?		
Do you have diabetes?		

Transcranial Stimulation safety-screening questionnaire! 2

	Yes	**No**
Are you pregnant or is there any chance that you might be?		
Do you hold a heavy goods vehicle driving license or bus license?		
Do you take psychiatric or neuroactive medication (e.g. antidepressants)?		
Do you suffer from frequent vertigos or headaches?		

	Yes	**No**
Is there any congenital deafness in your family?		
Do you have any hearing problems or ringing in your ears?		
Do you have a condition of your cervical vertebrae (e.g. spondyolysis, arthritis or scoliosis)?		
Are you taking any other medications? If yes, please describe below in which occasion(s).		
Have you ever had any adverse effects to TMS or tDCS in the past?		
Have you ever had a fainting spell, syncope or absence? If yes, please describe below in which occasion(s).		
Did you recently have a panic attack?		
Do you experience claustrophobia?		
Have you ever had any adverse effects to MRI?		
Do you have a skin disease (or did you have one in the past)?		

Additional information:
Name and contact details GP:

I have read and understood the questions above and I confirm that I have faithfully answered them.

SIGNED………………………………………………………….. DATE…………………………......................

In the presence of ………………………………….. (Name) ………………………………….. (Signature)

1

tDCS Monitoring Questionnaire!

As part of our research programme, we routinely monitor the health of participants following tDCS. We would be grateful if you could answer the questions listed below. Completing this form is entirely voluntary. The information you provide will be treated as confidential and will be held in secure conditions. Group results of this survey may be published, but no information will be disclosed that can identify any individual person. If you are unsure how to answer any of the questions, please ask the researcher who gave you this form.

Name: ……………………………………………………………………………………………

Current Date: ……………………………………………………………………………………

Date of Birth: ……………………………………………………………………………………

Handedness: ……………………………………………………………………………………

Please tell us if you experience any of the following symptoms. If the answer is YES to any of these questions, we would be grateful for additional details (please use the other side of this page)

Do you experience any of the following symptoms or side-effects?	Severeness (1=absent; 2=mild; 3=moderate; 4=severe)	If present : Is this related to tDCS? (1=none; 2=remote; 3=possible; 4=probable; 5=definite)
Headache		
Neck pain		
Scalp pain		
Tingling		
Itching		
Burning sensation		
Skin redness		
Sleepiness		
Trouble concentrating		
Acute mood change		
Others (please specify)		

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Transcranial Stimulation Pre-Session Screening

To minimise the risk of Transcranial Stimulation causing an adverse effect, it is important that you answer the following questions accurately before we begin the session.

	Yes	No
In the last 12 hours, have you consumed more than 3 units of alcohol?		
Have you taken recreational drugs in the last 24 hours?		
Did you get a good night's sleep last night, and do you feel alert?		
In the last two hours, have you consumed more than two cups of coffee?		

Date………………………………….

Name………………………………….

Signature…………………………….

tDCS Informed Consent

- I understand that I am to take part in a transcranial direct current stimulation (tDCS) experiment in which I will perform simple tasks, while tDCS is applied to specific parts of my brain.
- I confirm that I have read and understand the Volunteer Information Sheet and have had the opportunity to ask questions about it.
- I understand that tDCS carries a small risk of inducing syncope or cause other mild adverse effects, even in participants who pass the safety screening test.
- The risks and the possible consequences of transcranial stimulation have been explained to me by the investigator.
- I give the experimenter permission to contact my GP in case I experience any adverse effects of tDCS.
- Participation in this study is entirely voluntary and that I can withdraw from the study at any time without giving a reason.
- Non-participation or withdrawal from the study will not be of any disadvantage to my university career
- If I prematurely withdraw from the study I will still be appropriately compensated for my participation.
- I can instruct the researchers carrying out this study at any time to delete data obtained from me from their records.
- I am free to ask any questions at any time and that I can arrange to discuss any concerns with the lead researcher.
- At the end of the study I will be provided with additional information and feedback about the purpose of the study.
- No data will be published in which I can be identified individually. In accordance with the Data Protection Act, I can have access to my information at any time.
- The data provided by me in this experiment will be used for research purposes only. They will not be shared in any manner which would allow identification of my individual responses.
- Anonymised research data will be archived at the Economic and Social Data Service (ESDS), and might also be uploaded onto other digital data repositories, such as Figshare and the Exeter Data Archive, in line with current data sharing practices.

NAME! !……………………….................................

SIGNATURE!………………………..............................   !

DATE! !………………………..............................

Appendix 7 : Medicine list

Medicine list

- **Anti-depressants:**
  - Imipramine: Imipramine hydrochloride (im-ip-ram-een hi-droh-klo-ride) is a medicine which is used in depression and nocturnal enuresis. (NHS website)
  - Amitriptyline: Amitriptyline (Am-ee-trip-till-een hi-droh-clor-ride) is a medicine which is used in depression and nocturnal enuresis. (NHS website)
  - Doxepin (Brand names incl. Sinepin; Xepin): is a medicine which is used in depression and for the treatment of itching in those with eczema.
  - Nortriptyline (Brand names incl. Allegron): Nortriptyline (Nor-trip-till-een hi-droh-clor-ride) is a medicine which is used in depression and nocturnal enuresis. (NHS website)
  - Maprotiline: withdrawn in UK in 2005
- **Antipsychotics:**
  - Chlorpromazine (Brand names incl.: Chloractil, Largactil): Chlorpromazine hydrochloride (Chlor-proh-maz-een hi-droh-clor-ride) is a medicine which is used in a number of conditions - incl. schizophrenia and other psychoses, anxiety, and even nausea and vomiting. (NHS website)
  - Clozapine (Brand names incl. Clozaril, Denzapine): Clozapine (kloz-uh-peen) is a medicine which is used in schizophrenia.
- **Anti-viral (cytomegalovirus & herpes)**
  - Foscavir: Foscavir (Fos-ker-veer) is a medicine which is used in cytomegalovirus infections of the eye in people with acquired immunodeficiency syndrome and herpes simplex infections. Foscavir contains foscarnet sodium. It is supplied by AstraZeneca UK Limited. (NHS website)
  - Cymevene: Cymevene (Sy-mev-een) is a medicine which is used in cytomegalovirus infections. Cymevene contains ganciclovir sodium. It is supplied by Roche Products Limited. (NHS website)
- **Antiretroviral (HIV)**
  - Norvir: Norvir (Nor-veer) is a medicine which is used in HIV infection. Norvir contains ritonavir. It is supplied by AbbVie Limited. (NHS website)
- **General anesthetics:**
  - gamma-hydroxybutyrate (GHB): treatment of narcolepsy and alcoholism; recreational use: 'liquid ecstasy' . C drug in UK now
- **Bronchodilators (asthma)**
  - Theophylline (Brand Name(s) : Do-Do Chesteze, Franol-Plus, Nuelin SA, SLO-Phyllin, Uniphyllin Continus): Theophylline (Theeoff-illin) is a medicine which is used in asthma, chronic obstructive pulmonary disease, bronchitis and heart failure. Is not the same as the fast-acting inhaled bronchodilator. (NHS website)

See also Rossi et al, 2009 (p. 2026)

Appendix 8 : Participant debrief

DEBRIEF

The task you just completed is named "old/new recognition task". This is a very common task used in the literature to test individuals' ability to recognise faces and objects. The aim of the task is to help you become familiar with a set of faces or chequerboards and then test your ability to recognise these previously seen stimuli. The data produced by this task are usually accuracy (number of correct responses) and reaction time (the speed at which the response was made). Both these measures will be analysed to test your recognition performance.

Now, you probably noticed that some of the faces, or chequerboards you became familiar with, were then presented upside down! One of the most robust cognitive phenomena linked to recognition is the *face inversion effect*. This refers to a decrease in recognition performance when we see a familiar face turned upside down. This effect was discovered in 1969 (Yin, 1969) and, since then, has been used by researchers to explain how we recognise each others' faces. The overall aim of this experiment is to examine the inversion effect in regular faces and Thatcherised faces. These latter are simply regular faces in which the eyes and mouth have been turned upside down. This manipulation should stand out when the faces are upright but disappear when the faces are seen inverted, essentially making the inversion effect go away (or at least reduce it).

- tDCS is used, to examine how brain stimulation techniques can modulate the size of the inversion effect and, hence, increase or reduce individuals' ability to recognise faces.

If you have any questions, please don't hesitate to contact Dr Ciro Civile

(c.civile@exeter.ac.uk)

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